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Hydrologic Data

The Quality of Agricultural Research Service Watershed and Plot Data

U.S. Department of Agriculture

Agricultural Research Service

Agricultural Reviews and Manuals•ARM-W-31/August 1982

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The Quality of Agricultural Research Service Watershed and Plot Data

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U.S. Department of Agriculture
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Agricultural Reviews and Manuals•ARM-W-31/August 1982

FOREWORD

Background and Purpose

Experimental observations are the key to our understanding of natural phenomena and constitute an essential component of most major scientific discoveries. At the laboratory scale, these experimental observations can be, and generally are, made in carefully controlled environments. The level of control that is used in studies at this scale is usually matched to the accuracies desired and to the sensitivity of the measurements to environmental changes. As the physical scale of the process or system being studied continues to expand, the costs of environmental control escalate rapidly, ultimately compelling the scientist to use experimental approaches that are more appropriate for environments which are complex, transient, and largely uncontrolled. Experimental watersheds constitute "natural" research laboratories where complex hydrologic processes interact within a highly heterogeneous and poorly defined system to transform random, uncontrolled inputs into highly variable, time-dependent outputs. Not suprisingly, the experimental strategy and level of instrumentation for watershed studies demands compromise, with professional judgment establishing the optimum balance between the accuracy of system characterization and the human and financial resources available for conducting the study.

In evaluating the performance of such large complex systems where year to year responses frequently vary by an order of magnitude and where system responses at shorter time scales usually vary by several orders of magnitude, continuity of the recorded observations is often perceived as an overriding factor in experimental design. Depending on the study objectives and the resource constraints, accuracy and precision of some measurements may be justifiably sacrificed for increased durability and reliability of field instrumentation. Such research strategies have been and continue to be widely used in hydrologic studies, both nationally and internationally. During the past two decades, a rethinking of this research philosophy has occurred. In this period, our understanding of most of the key hydrologic processes that transform precipitation to streamflow has been substantially advanced. Furthermore, societal concerns about environmental degradation have necessitated significantly greater use of predictive procedures in developing broad planning strategies, and in establishing regulations and policies for environmental quality control. As a direct consequence of these developments, and the rapid advances in communications and computer technologies, the need to reassess earlier experimental strategies coupled with the need to evaluate the accuracy of hydrologic instrumentation over wider ranges of operating conditions, have been surfaced as important and potentially far-reaching issues by several ARS scientists.

In attempting to address these emerging program needs, Dr. T. J. Army, Deputy Administrator, NPS-ARS, requested that a survey be conducted to identify the key instrumentation and data quality concerns of the ARS watershed research program. This survey would document the data acquisition systems currently in use, would identify problems encountered in maintaining instrumentation performance, and would recommend instrumentation development and testing projects for inclusion in an agency program aimed at ensuring data quality. The material presented in this report represents the program's response to this request.

Instrumentation Needs and Recommendations

The instrumentation need mentioned most often in the report is flow measurement, particularly measurement of flows heavily laden with sediment. In addition to flow-measuring devices, a method of measuring flow depths other than by conventional stilling wells and float gages is needed to overcome stilling well lag and problems caused by sediment deposition.

The second major instrumentation need is for a sediment sampling system to withdraw representative samples that can be used to compute total sediment transport rates and sediment size distributions.

Electronic data acquisition, transmission, and reduction is a third major instrumentation need. The advantage of centralized data recording is that it will place all recording on a common time base and eliminate existing time synchronization problems. Backup battery power with the batteries charged by solar and wind generators is an auxiliary need. The effect of lightning on electronic systems is a problem mentioned in several reports. Experienced electronic technicians are essential to install and maintain modern instruments.

Other important needs and problems mentioned include adequate training of observers, effect of wind and snow on precipitation catches, difficulties with digital equipment, the adverse effects of travel restrictions, and lack of a national ARS effort to develop and test instruments and procedures for watershed research.

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REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM THE SOUTHWEST RANGELAND WATERSHED RESEARCH CENTER

by

K. G. Renard and Staff[1/]

INTRODUCTION

The mission of the Southwest Rangeland Watershed Research Center (SWRWRC) is to study the hydrology of rangeland watersheds and the effects of changing land uses and practices on the hydrologic cycle. This includes the study of rainfall, which is natural input to the watersheds; the quality and movement of water on the surface of the watershed; erosion from the watersheds and from the channels within them; sedimentation within the channels and reservoirs; and the present and potential uses of available water. Primary emphasis is on:

(1) Understanding and evaluating the effects of changing land use, including range renovations and conservation practices, and

(2) Developing the principles for such understanding in order to apply the results and findings from research areas to areas having little or no research data.

Scientists at the Research Center use the data from experimental areas in Arizona and New Mexico to study the quality and quantity of water from southwestern rangelands. Information obtained from these rangeland watersheds is used to determine the present and future potential water resources of the watersheds, which includes managing the use of the water for competing local and downstream users; establishing soil, water, and grazing management systems for increasing and stabilizing forage production; providing design concepts and criteria for flash flood and sedimentation control; and monitoring the movement of nonpoint source pollutants on semiarid rangelands. Simulation models have been developed that transfer climatologic and hydrologic data and concepts to predict the hydrologic response of ungaged areas.

The work at what is now the Southwest Rangeland Watershed Research Center was initiated by the Research Division of the Soil Conservation Service (SCS) in the late 1930's with the work on small watersheds near Safford, AZ and Albuquerque NM. Work on the Walnut Gulch Experimental Watershed, in southeastern Arizona, and the Alamogordo Creek Experimental Watershed, near Santa Rosa in eastern New Mexico, was initiated at about the same time that the research program of SCS was transferred to the newly formed Agricultural Research Service (ARS) in 1954. Research on these new larger watersheds soon showed that there were serious problems with streamflow measurement, and that there was an urgent need for a precalibrated measuring device capable of accurately measuring flow even when it carried heavy sediment loads and when flow rates fluctuated widely and rapidly.

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DATA AQUISITION PROGRAM

2.1 Precipitation: Precipitation studies in the southwestern United States are unique because of the dominance of high-intensity air-mass thunderstorms of limited areal extent that dominate the annual precipitation totals. About 2/3 of the annual precipitation total of 10 to 20 inches occurs during the summer monsoon season. Accurate definition of such storms requires a dense network of recording raingages, which creates some unique maintenance problems. The problems include the demands for servicing the mechanical recorders (they must be serviced weekly, or even more often during stormy periods), digitizing the records for subsequent analysis, and finally, maintaining the mechanical components (including the clocks). At the SWRWRC, a significant amount of the financial and people resources have been devoted to this problem. The weighing-type raingages currently used in this work are almost 40 years old and, although they operate well, could be improved with a central recording system, especially for synchronizing the time base of the hydrologic network. Furthermore, the existing raingages are not capable of describing the dynamic nature of rainfall rates. The differentiation of the integrated pen trace produced by the existing weighing record is subject to considerable subjective (operator of the digitizer) error. The rainfall intensity for very short periods (less than 5 minutes) is important to infiltration work and for erosion studies.

Approximately 90 scientific papers have been prepared by the Center staff describing the climatic/precipitation characteristics of the region. Osborn et al. (1972) stated that 1400 raingages would be required on Walnut Gulch to ensure a correlation coefficient (r) of 0.9 between adjacent gages (a spacing of 1000 feet). Renard and Brakensiek (1976) prepared a synopsis of the precipitation patterns in the western United States and contrasted seasonal characteristics within the region.

2.2 Runoff: Runoff in ephemeral streams creates some extraordinary problems of measurement. The streamflow is generally of short duration -- a response to periods of excess precipitation that are characterized by extreme spatial and temporal variability. The channels, which are dry 99.9% of the year, are characteristically steep (0.5 to 5.0%), with the result that the flow velocity is often near that for critical depth. Furthermore, the sediment supply is essentially infinite, so that the sediment transport rate (both suspended and bedload) is high. The combination of high velocities, rapidly changing flow depths (depth changes of >1.0 foot per minute), and high sediment loads preclude field measurements with conventional technology like current meters. Thus, precalibrated measuring devices (laboratory-rated devices) are essential in obtaining quality data. These problems led to a significant effort by scientists at the SWRWRC and at the Stillwater, Oklahoma Water Conservation Structures Laboratory to develop a supercritical measuring device for these flow characteristics. The details of these supercritical flumes, their rating problems, as well as problems of construction and operation, have been described by Osborn et al. (1963), Gwinn (1964), Quashu et al. (1966), Gwinn (1970), Smith and Lane (1971), Smith and Chery (1974), and Smith et al. (1981) (see figures 1, 2, and 3).

Efforts to obtain prototype verification of these laboratory-rated flumes have also been extensive, and have occupied a sizeable portion of the staff time and funds. For the 10-year period from 1961 to 1970, funds were transferred from the SWRWRC to the Stillwater, Oklahoma laboratory for partial support of the flow measurement research. Thus, each of the supercritical measuring flumes constructed at the larger watersheds operated by the Center (watersheds >500 acres) were individually laboratory rated, which involved building a scale model of both the flume and the upstream and downstream channel.

Prototype verification involved: (1) observations of the water surface profiles in the approach channel and in the flume itself; (2) low flow ratings using a current meter; (3) larger scale-models of the flume floor section; (4) use of dyes with

constant injection for dilution testing; (5) use of a magnetic induction velocity meter to measure velocity; and (6) full-scale model testing of a prototype involving a modification of the Walnut Gulch flume which was subsequently named a Santa Rita flume.

Fig. 1. A view of the flume completed at the outlet of the 58 sq. mi. Walnut Gulch Experimental Watershed in June 1954. The small flow on this date was held in the barrow pit associated with the construction. The structure was destroyed by flows during the first runoff season.

Details regarding most of this prototype verification are included in the USDA Technical Bulletin entitled, "Supercritical Flow Flumes for Measurement of Sediment Laden Flow", by Smith et al. (1981). The prototype verification work involving measurement with fluorescent dyes on Walnut Gulch, (at Flumes 6 and 1), was only partially successful. Rhodamine WT and Pontacyl pink dyes were injected at constant discharges across the flow width immediately upstream from the measuring station. Samples were collected about 500 feet below the flume after the flow had been mixed in the hydraulic jump. Unfortunately, the dyes used, although water soluable, also adhered to the clay fractions in the flow. Thus, concentrations of the dye in the mixed sample were sensitive to the time after the sample collection at which the fluorometer measurements were taken, with an approximate error rate of 50% involved in only a 6- to 12-hour delay. Attempts were made to use a salt for the tracer. However, the Arizona State Health Board would not approve use of the fluoride salt, and most other salts investigated had appreciable, but not consistent, background loads in the runoff from the area.

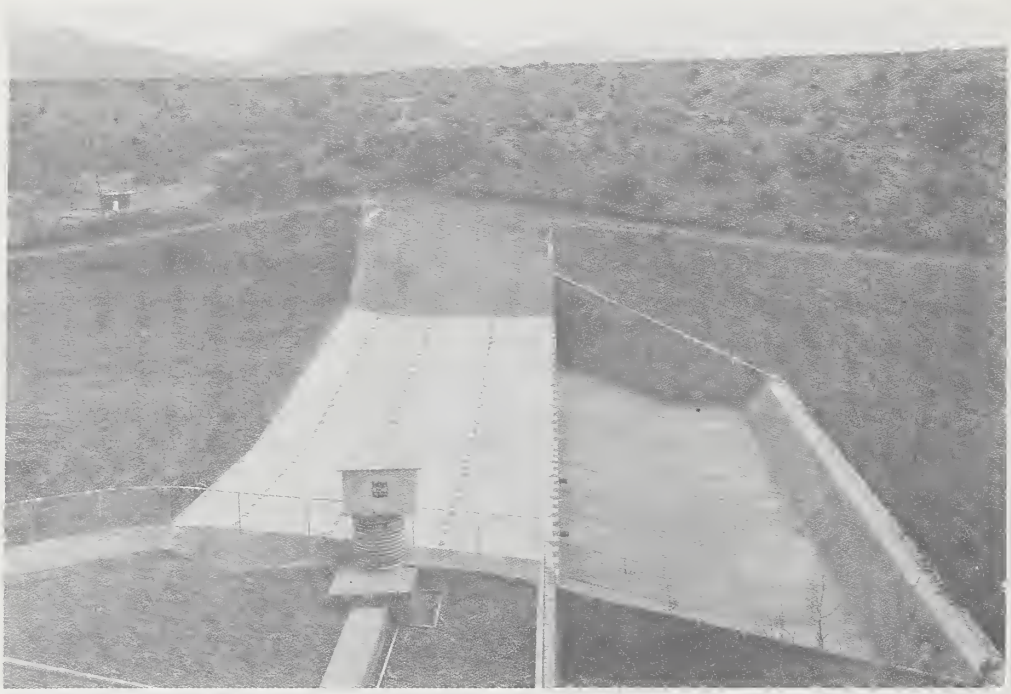

Fig. 2. A view of the runoff measuring structure at the outlet of the Walnut Gulch Experimental Watershed completed in 1964. The energy dissipator in the right portion of the picture was required to prevent scour and increased the cost of the structure. When the bedrock is capable of dissipating the energy, this additional concrete is not required. The new structure is much larger than the original (22,000 cfs vs. 5,000 cfs).

Runoff measurements (rates and volumes) have also been made and are continuing in connection with plot studies at the SWRWRC. Some of the earlier studies involved volumetric measurements only. Subsequently, a volumetric tank was equipped with a water level recorder and an orifice part way up the tank. Thus, outflow from the plot was determined from a combination of volume change plus the discharge from the orifice. Accurate runoff measurements were obtained with this method, although some problems were encountered with trash collecting on the screen behind the orifice. Unfortunately, the method cannot be used to measure sediment loss.

In some recent work with a rotating boom rainfall simulator for determining plot erosion, some very small flumes (0.05 ft floor width and 0.50 ft deep) were developed (Santa Rita flume design). Aliquots of the water/sediment/chemical mixture are obtained at the flume exit. This also has proven quite satisfactory, although a sloping approach box and plot trough must be used to ensure that sediment does not deposit in the approach and measuring section. The use of supercritical measuring devices does result in some loss of sensitivity in the depth-discharge relationship.

2.3 Sediment Concentration: Perhaps one of the more important problems of measurement in watershed research is that associated with erosion/sediment transport/sediment yield research. In our estimation, this is one of the more serious problems we have

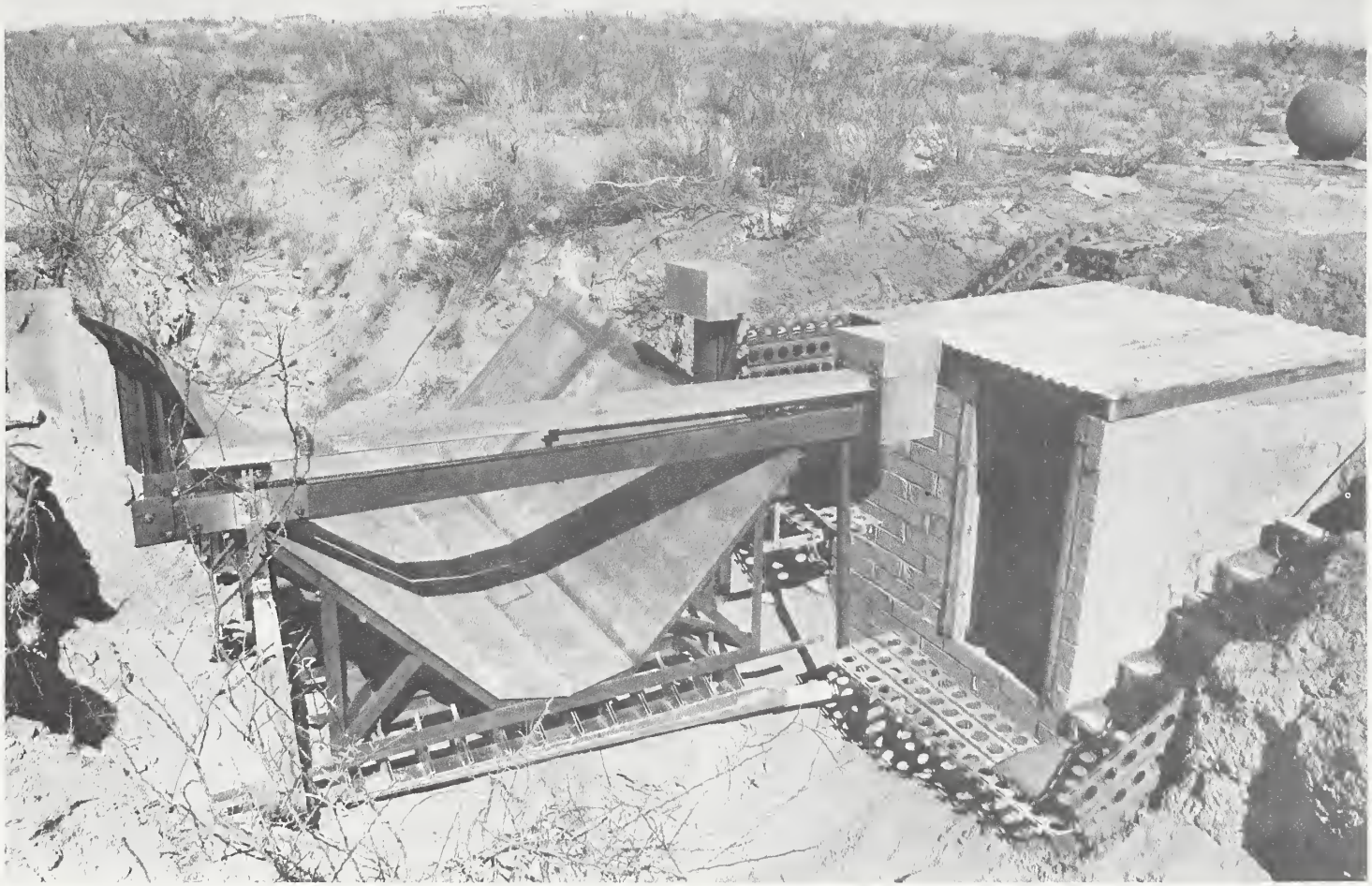

Fig. 3. The Santa Rita-type supercritical measuring flume shown has a peak measuring capacity of 100 cfs. This prefabricated measuring device has been equipped for water quality sampling. Aliquots of the water-sediment-chemical mixture are collect at the overfall with the traversing slot (at left edge of flume) and deposited in the shelter house in the right foreground. The structure is 3 feet deep at the flume exit.

encountered. The state-of-the-art technology here has lagged seriously behind other facets of our work. By and large, field data are still being collected using equipment developed decades ago, although the advent of pumping samplers has helped to provide samples at remote sites throughout individual storm events.

At the SWRWRC, a concerted effort was made in the mid 1970's to develop sampling equipment capable of sampling the entire flow cross-section. The sampling scheme developed, which is currently used at most small watersheds (peak flows <100 cfs), involves a moveable slot that traverses the flow, diverting an aliquot of the flume outflow (water/sediment mixture) onto some fixed slots. The fixed slots further reduce the sample size (figure 3). The subsequent split is deposited in a modified Chickasha-type sampler table, with each sample then being associated with a discrete time on the hydrograph. The unit, which operates from batteries charged by a photovoltaic charger, has a variable speed drive mechanism for the moveable slot. The speed control allows the desired sample size to be obtained regardless of the flume discharge rate. Construction of these units with stainless steel, galvanized sheet metal, or plastic ensures that the aliquots can also be used for chemical concentration determinations. Details of this sampling scheme are given by Renard et al. (1976). Recent unpublished modifications of this sampler include a constant speed for the traversing slot with the end of sampling preset when each bottle is half filled.

Pumping samplers used at some runoff-measuring stations with H-flumes, have unique problems associated with the sampler intake. The intakes used at SWRWRC are patterned after those used at Coshocton, OH and consist of a pipe with equally spaced holes, mounted and hinged at the streambed, and buoyed by a float at the end. These devices sample the entire flow depth. Questions regarding the sampling efficiency for holes in the upstream, downstream, or sides of the pipes need to be resolved. Similarly, such a device may provide reasonable estimates of the finer sediment fractions but ignores the load moving in close contact wth the streambed. There are also unresolved problems associated with debris collecting on the pipe and restricting the flow through one or more intakes.

Our observation has been that there are severe problems associated with sediment sampling at many experimental sites. State-of-the-art procedures are to pump an aliquot of the water/sediment/chemical mixture from a fixed position in some portion of a flume or weir. At best, such a scheme raises serious questions. The suspended sediment concentration can be described by (Rouse, 1949, p. 800):

$$\frac{C}{C_a} = \exp\left(\frac{-w(y-a)}{\varepsilon}\right)$$

where C = the concentration of sediment at a distance y above the bed,
C_a = the concentration at some reference level a, above the bed,
w = the fall velocity of sediment particles in the fluid,
and ε = the sediment transfer coefficient

Thus, the concentration of pump samples must be corrected because they are collected at a depth whose relation to the total depth is changing throughout the hydrograph. Current efforts generally ignore this problem and generally ignore the problem of the coarse fraction moving close to the bed (usually referred to as bedload). In many environments, the so-called bedload discharge can be a significant fraction of the total load -- our experience with H-flumes is that the bedload is often twice the suspended load.

At the large watersheds on Walnut Gulch, samples for determination of suspended sediment concentration are collected using equal-transit-rate principles with US-D-48 hand samplers when we can wade the flow. When the flow is too deep for wading, a US-P-63 depth-integrating sampler is lowered from a cableway. Such measurements are

generally made at only two of the watershed locations because of manpower constraints. When the cableway sampling procedure is used, samples are generally collected at, or near, the channel centerline. These procedures also can introduce considerable error, because the samples from one cross-section hardly represent the mean for the section. Because of the rapidly changing flow depths, this is the best information that can be obtained using currently available equipment. Bedload or coarse material transport at the flume exit is determined periodically using a traversing slot. The data indicate that bedload transport is highly variable, not necessarily proportional to the water discharge rate but, rather, associated with passage of dunes and/or antidunes through the measuring flume.

2.4 Chemical Transport (Concentration): The concentration of dissolved and adsorbed chemicals in the runoff from experimental watersheds operated by the SWRWRC is closely related to the sediment sampling. Where the traversing slot samplers are located with Santa Rita-type flumes, the concentrations of cations and anions represent good estimates of the concentrations of the flow. Laboratory equipment that we use for the concentration determinations include atomic adsorption spectrophotometer and a Technicon* autoanalyzer, which are considered to be the best techniques currently available. When adsorbed chemicals are involved, the data problems associated with the representativeness of the sediment sample also can be assumed to apply. The traversing slot samplers, as mentioned earlier, are constructed using materials that should minimize contaminations.

Chemical composition of precipitation has also been monitored by the SWRWRC using equipment designed by Schreiber and Cooper (1978). Heavy sulfur concentrations (pH <4) have been measured with some frequency (Osborn and Cooper, 1981). The equipment seems to work very well.

DATA QUALITY PROBLEMS

3.1 Precipitation: One major problem with the precipitation studies is that each sampling point uses an independent time reference (clock). Therefore, in attempts to describe the timing of thunderstorm cell buildup, the lack of synchronization can cause timing errors to become very significant. As an illustration, consider a room full of people, each with his own wristwatch. Although the mean time is probably near the actual time, the deviation from that mean is likely to be appreciable, with a range of, perhaps, ±10 to 15 minutes. Our raingage clocks are similarly independent. Furthermore, the 24-hour per revolution time scale used by the raingages operated at the SWRWRC means that intensities for short time intervals are subject to large error (e.g., a 2-min intensity may well be ±50%). Central recording with electronics, such as that being used by the USDA Sedimentation Laboratory for the Goodwin Creek study in Mississippi, appears to be a viable alternative. Unfortunately, the resources required for such a network would require a large one-time commitment of funds, which is not feasible with the funding currently available at the project.

3.2 Runoff: The runoff devices used at the SWRWRC are, in our estimation, the best currently available. If the number of requests for design information are an indication, quite a few of our peers agree with us. Furthermore, the correct utilization of information presented in Chapter 2, Runoff, in Agricultural Handbook 224 (Brakensiek, et al., 1979), should minimize improper use of runoff-measuring devices by engineers and scientists designing data collection programs for water resources research. Unfortunately, people using runoff measurement information often have not had adequate training to assist them in selection of an appropriate device.

*Trade names are included for information of the reader and do not constitute endorsement by the United States Department of Agriculture.

There are, however, problems at both our locations and in general with runoff records because of difficulties with station maintenance. The problems have involved such things as plugged intakes, improper setting of the point of zero flow, and making improper adjustments in water-level recorders. Many of these problems result from inadequate training of field personnel, poor communication between the field people and the data processing people, use of shortcuts, or inadequate understanding of the possible errors involved (data sensitivity). Perhaps the USDA-ARS agency should develop some training guidelines for present and new employees.

3.3 Sediment Concentration: Many of the problems with sediment concentration are associated with selection of an appropriate sampling point. Current sampling techniques generally consist of collecting a sample at a fixed point in converging or diverging flow in a flow measurement device. Information is insufficient in the literature to assist in a logical decision for such problems. Furthermore, procedures need to be developed for correcting or adjusting point sampling data to that representative of the whole flow cross section.

Once a sample is collected, the time-consuming methods for determining both the concentration and the particle-size distributions cause problems. The particle-size distribution has assumed tremendous significance in the last decade because of interest in water quality and the role of sediments as scavengers and transporters of various chemicals. A recent study by Schiebe, Welch, and Cooper (unpublished report, 1981) indicates that some of the new equipment used for particle size determination give widely different results as compared with the conventional pipette method. Work to improve the speed of determining partice-size distribution is very important, and furthermore, research is needed to define the role of aggregates versus primary particles in both sediment and chemical transport.

In summary, although we recognize that there are many problems with data on sediment concentration, we suggest ARS may be in a position to be the leader, both nationally and internationally, in developing more accurate methods of sampling for sediment in flow.

3.4 Chemical Concentration: Research at the SWRWRC on chemical concentrations associated with runoff has not involved a major commitment on our part. If runoff water quality determinations are to be meaningful, instrumentation must also consider rainwater composition. Thus, it is difficult for us to state the potential problems with such data. Many such programs, however, do involve samples that decompose in time because of high temperatures. Thus, the sampling equipment must be serviced frequently, and time dependent concentrations must be determined immediately, which often means that employees must work overtime or, at best, samples must be refrigerated. Thus, the research requires accurate runoff data, accurate sediment concentration data (for determining concentrations of adsorbed chemicals), and then accurate laboratory equipment for chemical concentration measurement.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

1. Test the sampling efficiency of the traversing slot sampler. For example, we assume that the aliquot entering the slot is representative of the sediment in transport, but the assumption has not been verified. Such verification would be somewhat like what has been done for samplers developed by the Federal Interagency Sedimentation Project in Minneapolis.

2. Develop reliable means for indirect measurement of flow depths to eliminate intake lags in conventional water-level recorder systems. Check bubble gages versus conventional water-level recorders as a means of replacing intake systems which are subject to sediment plugging. Define the drawdown caused by water moving over slotted plates.

3. Develop criteria and equipment for measuring in situ concentrations of sediment and chemicals. Such a program would also require definition of the best location within a control section for collecting such data (for example, at converging or diverging sections of the flow, or, perhaps turbulence could be introduced below a measuring station to facilitate more representative sampling).

4. Develop an efficient and economical telemetering and data recording system for hydrologic instruments including raingages, water-level recorders, soil moisture and water quality samplers. Such work should also include developing transducers to sense the hydrologic signals which might include using radar, sonar, lasers, etc.

5. Develop equipment to monitor the position of a streambed during the passage of an individual flood wave.

6. Develop training programs to teach continuing or new employees the best techniques available for recording hydrologic data.

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REPORT ON QUALITY OF PESTICIDE RUNOFF DATA FROM THE SOIL AND WATER MANAGEMENT RESEARCH UNIT, RIVERSIDE, CA

by

W. F. Spencer

INTRODUCTION

The mission of the unit is to develop methods for evaluating, predicting and reducing pollution of soil, water, and air by pesticides. The research program includes field and laboratory experiments to determine the amounts of pesticides in surface runoff and ground water as affected by pesticide application and irrigation management practices. For this purpose we are measuring amounts of pesticides in irrigation return flows from surface irrigation runoff water and tile drainage water from large fields under various irrigation practices used by farmers in the Imperial Valley of Southern California. The fields, varying in size from 14 to 65 ha, were instrumented for measuring water volumes by Lee Hermsmeier and other personnel of the USDA-ARS Imperial Valley Conservation Research Center, Brawley, California.

DATA ACQUISITION PROGRAM

2.2 Runoff: The fields are instrumented with propellor water meters for measuring incoming irrigation water, Parshall flumes for measuring outgoing runoff water, and slotted tubes on tilelines for measuring tile drainage water. The fields are surface irrigated with furrow or border irrigation systems. Since most of the pesticides in irrigation return flows are found in the surface-runoff water, the measurement of runoff volume is of major concern in calculating total pesticide runoff during each irrigation event. We use Parshall flumes varying in size from 12 - 24 inches. Proper widths are chosen for the expected runoff volume based on the size of fields and the irrigation management practiced by the farmer. Parshall flumes are leveled carefully, and the elevation of the crest is chosen with reference to the bed of the runoff ditch to minimize the possibility of submergence. Water stage recorders are used to measure flow through all flumes. On flumes where submergence may occur because of drop inlets placed just downstream from the flume outlet, a second water stage recorder is installed at the throat of the flume. All flumes have staff gauges at two positions, i.e., in the converging section and at the throat of the flume to periodically check for submergence during peak runoff periods. The staff gauges are read at each sampling time to compare manually-read flow volume measurement with that obtained on the water stage recorders. The runoff water is relatively low in sediment, usually less than 1 - 2 g/L, consequently sediment is not a problem influencing flow volume measurements.

Screens installed at the incoming end of the irrigation pipe protect the propellor meter from being clogged by trash in the irrigation canal. Slotted tubes for measuring flow from the tile lines are calibrated with a bucket and stop watch.

2.4 Water Quality: Pesticide concentrations are being measured periodically and the total amounts of pesticides removed from the treated fields in runoff and tile drain waters are calculated from flow volumes and pesticide concentrations. The farmers determine which crops are to be grown on the fields and which pesticides are to be applied. Pesticides are applied by aerial application or ground rig, or directly in irrigation water during the growth of the crop. Based on the relationship between pesticide concentration and the runoff hydrograph, we sample runoff water most frequently during the first irrigation after a pesticide application, usually at ½ to 1 hour intervals. For the second irrigation, samples are taken at approximately ½

hour intervals for only the first two or three hours after start of runoff, and then at 2 to 4 hour intervals. For subsequent irrigations samples are taken 4 to 6 times per event. Sample integrity, with regard to stability of pesticides, is maintained by transporting the samples under ice and storing at 4°C. The water samples are buffered at collection time with 2 g/L potassium dihydrogen phosphate (KH_2PO_4). Quality assurance for laboratory analysis is gained through fortification and recovery studies in the laboratory and through a quality assurance study involving analysis of split water samples by three other federal laboratories (USGS, EPA, and FDA).

DATA QUALITY PROBLEMS

3.2 Runoff: Problems encountered in maintaining instrumentation performance and site conditions include: (a) Occasional malfunction of chart recorders. If a chart recorder malfunctions we rely on staff gauge readings at sampling time for runoff volume estimates. In the absence of sufficient staff gauge readings, total flow volumes for the purpose of calculating total pesticide runoff are estimated from similar irrigation events. (b) Submerged or overflow conditions where drop inlets into the main drain ditch are not large enough to take the volumes of water released by the irrigator. For submerged conditions, flow volumes are corrected for submergence according to methods discussed by Parshall (1950). Flow volumes during flume overflow are estimated from the maximum capacity of the drop inlet calculated from head readings and size of the drop inlet.

3.4 Water Quality: We observed that some organophosphate insecticides, including ethyl and methyl parathion and diazinon, were unstable during storage of the runoff samples even at 4°C because of an unusually high pH brought about by the application of ammonia, either to the irrigation water, or as a side dressing to the crop sometime prior to irrigation. We have found that adding 2 g/L KH_2PO_4 to the water samples immediately after they are obtained from the runoff flume prevents this degradation. Samples are then transported in ice and extracted with minimum storage at 4°C after arrival in the laboratory.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

The development of portable flow measuring devices for installation in irrigation return flow ditches to estimate the amount of surface runoff to within $\pm$ 10 to 15% would be useful in conjunction with sampling for pesticide concentrations to estimate total pesticide loss from treated fields under various soil, crop, and water management conditions. Most of the present devices are too cumbersome and bulky to move from field to field for this purpose or they require a stabilized ditch, such as a concrete irrigation channel.

REFERENCES

(1) Parshall, R. L. Measuring Water in Irrigation Channels with Parshall Flumes and Small Weirs, USDA, Soil Conservation Service Circular No. 843, May 1950, Washington, D.C.

REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM THE AGRICULTURAL/SURFACE-MINED HYDROLOGY RESEARCH GROUP FORT COLLINS, COLORADO

by

D. G. DeCoursey and Staff

INTRODUCTION

The mission of the Agricultural/Surface-mined Hydrology research unit is to measure and understand basic hydrologic processes and plant-soil-water relations so that we can develop better watershed management practices for agricultural and surface-mined areas and can predict the environmental effects of such practices. Objectives of this research are: (1) To develop stochastic and deterministic mathematical models of hydrology systems and to devise methods for estimating model parameters for ungaged areas; (2) to develop information and technology that can be applied to reduce non-point source pollution from agriculture; (3) to develop information and technology that can be applied to prevent or reduce erosion and surface and groundwater degradation caused by surface mining; (4) to develop criteria for evaluating the chemical suitability of overburden and mixed soil materials for revegetation and to develop corrective measures for unsuitable spoil materials; (5) to quantify the rates of nitrogen flow via the nitrogen cycling processes of mineralization, immobilization, denitrification, etc. in a disturbed land ecosystem and to evaluate its significance for plant growth; and (6) to determine regimens for revegetation of strip mine areas.

At the present time major emphasis is being placed on estimating the effect of various management practices on the movement of water, sediment and chemicals from surface mined lands and in the development of mathematical models of hydrologic systems, both field and small watershed size areas. The productivity and nitrogen use efficiency of various mine spoil vegetative treatments are also being investigated. Accurate records of rainfall, runoff, sediment concentrations, meteorological conditions and chemical concentrations are needed to support these research projects.

DATA ACQUISITION PROGRAM

All precipitation, runoff/streamflow, sediment concentration and chemical concentration data collected by the Agricultural/Surface-Mined Hydrology Research Group are from plots and watersheds located in Routt County, Colorado, about 22 miles southwest of Steamboat Springs. The location is in the mountainous regions of northern Colorado at an elevation of about 7,000 feet in an area of extensive surface mining activity. Much of the hydrologic activity is associated with the snowmelt season, although some runoff is associated with summertime thunderstorms. Accessibility is the single most significiant problem associated with data collection. Deep snow in the winter makes travel difficult, however, the most severe problems are experienced in the spring snowmelt season (the most active hydrologic period) when muddy conditions make travel almost impossible. This reduces the quality of data because of limited visits (sometimes the sites are inaccessible). Since much of the data are collected in a relatively short period of time it is impractical to permanently locate personnel at the site, therefore, the collection of most of the hydrologic data is performed by contract with a consulting geologist.

Precipitation. Average annual precipitation is about 50 cm and is distributed quite uniformly through the year, but because of cold temperatures over half of it falls as snow. Rainfall in the summer months occurs as a result of thunderstorms; thus, high intensities and some runoff are possible. Topographic variation and small cell development in the summer period lead to significant spatial variability. Few roads and the problems of accessibility in the Winter-Spring months make it impossible to place enough gages to adequately monitor the temporal and spatial variability of precipitation input. Precipitation stations are maintained year round at most of the runoff measuring stations and during the summer at the simulator plot sites. Weighing-type recording raingages are used at all sites. Antifreeze is used in the winter to prevent freezing. The water content of the snowpack at two sites is measured using gamma attenuation procedures. Records of both rainfall and snow depth could be improved through the addition of more gages and the use of a telemetry system to record or send the data to a master station thus improving the time base of the records.

Runoff. Runoff records collected in conjunction with the research program on surface mine hydrology consist of three different instrument systems. One is HS type flume and FW-1 water level recorders for use on the rainfall simulator plots. The others are a supercritical flume and conventional stream flow monitoring stations. The HS flume and FW-1 water level recorders are installed in a conventional way. Stevens-A-35 water level recorders are used to monitor the flow in the supercritical flume and stream channels. High sediment concentrations cause some problems with stage measurement, but the flow records are influenced more by ice. An enclosed and heated canopy over the flume minimizes this problem. Use of the supercritical flume as a measuring device results in some loss of sensitivity in the rating, but allows measurement in an otherwise quite different situation. The streamflow measuring stations, as well as the supercritical flume experience rapidly changing flows during thunderstorm runoff periods. During the spring snowmelt period the runoff shows significant diurnal variation. Even though the streamflow runoff stations show rapid response to rainfall and snowmelt, their velocities are not high because of the effect of beaver ponds. The beaver activity often creates an unstable rating at most of the stations. Artificial controls of rock (or rubble dams) are used to minimize the effect of the beaver activity and create a stable record. However, the beaver activity and high flows require constant checks on the rating and repair of the control dams. Freezing of stilling wells and the channels in the winter and spring period create additional problems of record accuracy.

Sediment Concentration. Sediment concentrations are the most difficult records to collect and are the least accurate. On the small runoff plots where the entire flow for a short period of time can be collected in a single bottle, the sample is accurate. Samples of water and sediment from the streamflow stations are obtained from automatic pumping samplers pumping from a fixed point in the flow. The point samples are related to the average of the cross section by taking equal transit rate samples by hand, when possible. Both samples collect only the suspended load. The material moving in close proximity to the bed must be estimated. Sediment samples from a small disturbed lands site are pumped from a point at the upstream end of a supercritical flume. Representativeness of samples is not known because most of the runoff occurs during the spring snowmelt season when accessibility to collect manual equal transist rate (ETRs) samples is almost impossible.

Chemical Concentrations. Chemicals carried in runoff waters are both in solution and adsorbed on the organic and clay particles. Except for grab samples collected at various specific sources such as seeps and small runoff plots, all samples for chemical analyses are collected by pump samplers at irregular intervals depending upon research plans. These samples are probably quite good and representative for the dissolved species, but are no more accurate than the sediment samples for the adsorbed species.

DATA QUALITY PROBLEMS

Precipitation. The major problem with precipitation is lack of representative measures of spatial variability in both snow accumulation and rainfall. Drifting of snow leads to wide variations in accumulated depths which cannot be accurately measured due to high cost. Rainfall in the region is primarily of a small cell thunderstorm nature. This and orographic effects lead to large spatial variability. Since costs and accessibility limit the number of sites, estimates of catchment rainfall are poor. However, since many of the studies are associated with small plots, point measures of precipitation are fairly reliable estimates of plot rainfall. Other sources of error include i) independent records of time at each site, ii) the instrument lag and paper expansion problems that lead to errors in estimates of intensity, and iii) the effect of wind on the catch of a conventional raingage. It is questionable whether surface gages and central electronic recording of rainfall, to minimize the above possibilities of error, are justified in light of the problems of spatial variability. They may be justified on the plots, but even there costs may be prohibitive.

Runoff. Runoff records from both the plots and small watersheds are probably the most accurate of all records. This is especially true for the small plots where HS type flumes or the supercritical flume are used. In the small streams, the rating curves are frequently checked because of problems associated with beavers and the effect of large events on the artificial controls created by small rock dams. In addition to these minor problems, there are the usual problems associated with instrumentation and station maintenance, i.e. setting of gage zero, time, etc. These are considered to be a major problem here.

Sediment Concentration. Problems of accuracy in sediment concentration estimates come primarily from the representativeness of point samples as compared to cross section average. This is especially true of samples taken from the supercritical flume where changes in the approach channel cause the tongue of bed material load to shift. This leads to extremely unreliable estimates based on the pumped samples. Samples of sediment concentration at the stream channel stations are more reliable in their estimate of the suspended load, but do not provide any measure of the bed material load. Other problems include estimates of the particle size distribution. Conventional methods of obtaining the particle size distribution of materials in transport break down natural aggregates, thus estimates of transport capacity of the material are affected. Better methods of obtaining the particle size distribution of the actual materials in transit are needed, because of their effect on both transportability and chemical relationships. The size of these errors is not known.

Chemical Concentration. The most significant problems of chemical concentration are those associated with errors in the sediment concentration. Since there is always a lag in getting the samples analyzed for chemical concentration, there is opportunity for changes or decomposition in the chemical make-up. This problem is

confounded, if the sediment concentrations of the sample are not representative of the whole cross section, because of the adsorption-desorption isotherms that relate the amount of adsorbed chemical to the amount in solution. If the flow in the channel is assumed to be in equilibrium and samples are collected that are excessively high or low in sediment concentrations, then changes can take place in the stored samples that will not be representative of channel conditions. Even in view of these potential problems, the quality of the chemical concentrations collected at this location are assumed to be good, partially because of the chemicals being evaluated.

Recommendations for Instrument Research. Perhaps the single most pressing need in instrument development is in the area of sediment transport and sediment concentrations. At the present time only suspended load samples are obtained at most stations, bed material load must be estimated. At a few locations where the entire flow passes through a flume, such as the supercritical flume, the opportunity exists to sample the entire load. This can be done at a few locations where the peak flows are not excessive and the flow depths are shallow enough to use a sampler such as the traversing slot sampler used at Tucson. However, at other stations where flow rates are high or depths too great to sample adequately, samples are being obtained by pumping samples from the approach channel, the flume, or a turbulence box upstream or downstream from the flume. The adequacy of these samples is questionable because of continuously changing approach conditions and the fact that pumped samples limit the sample to particle sizes that can be handled by the pump. Pumped samples also change the particle size distribution of the sediment because of the impact of the pump on particle aggregates. These problems point to the need for extensive instrument and sampling technique development.

Other equipment and instrument development include the remote monitoring of both the surface and bed of natural channels to accurately reflect the changes that take place during a flood flow. In situ measurement of both sediment and chemical concentrations that would eliminate the time consuming, costly and inefficient laboratory analyses are also urgently needed. An accurate assessment of the effect of wind on conventional raingage catch that could be used to correct the record for true ground surface measurements is needed. Accurate estimates of rainfall intensity, especially on small runoff plots are still needed.

Table 1. Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Universal Rain Gages	Consistency of chart and accumulated rain weight	Yearly maintenance and calibration Reference to brass tube measurement
	Gages inaccessible during snow conditions	Use electric clocks
	Electric clocks fail in extreme cold weather	Place two most accessible gages on manual wind-up clocks
	Clock failure	Keep spares and regular maintenance
	Ice	Antifreeze added routinely in freezing months
	Intensity for summer storms not precise enough	Put on 24 hr gears and charts
	Areal representation	Sites chosen for exposure and research needs
Remote Snow Sensors	Scatter due to radiation source material	Two gages set out for comparison-sampling at 8 hr intervals
	Accuracy of instrument calibration curves	Use manual digital readings and snow surveys around gages for comparison
	Electronics in gages malfunction in extremely cold weather	Have paper tape backup and printout
2.2 Runoff/Streamflow/Groundwater:		
Streamflow gaging network	Unstable controls due to beavers, channel erosion and extreme events	Use rock dams and frequent use of current meter measurements
	Sediment deposition in approach	Use precalibrated supercritical flumes
	Severe icing	Use enclosures and heaters
	Recorder failure or of questionable quality	Frequent servicing and use of back up recorders
	Stilling wells freeze up during winter	Use electric stock-tank heater or styrofoam on water surface
	Confusing reversals on 1 H stage chart	Install 5 ft stage gears
	Staff gage and inner gage heights do not agree	Check with plumb-bob measurement from a known elevation to the water surface in the stilling well. Check intake lines for blockage.
Observation Well	Have none of our own	Obtain data from study done in area by Colorado School of Mines

Instrument description	Problem situations	Action taken to insure data quality
2.3 Sedimentation:		
Suspended sediment sampling	Questionable sampling accuracy	Values compared to ETR samples, samples pumped from region of high turbulence
	Pumping sampler failure	Install more reliable samplers
	Pump sampler intake hoses frozen overnight	Place sampler in heated building
	Intake clogged with large particles of mine spoil	Cover end with screen
2.4 Water Quality:		
Chemical concentrations	Temporal changes	Monthly data supplied by samples collected at more frequent intervals
	Analyses variability	Computerized check for lab error in sample analysis
	Quality of sample analyses	Periodic checks with sample of known content

Table 2. Data Quality Evaluation

Description of current stations	Number of stations	Estimate of Data Quality	Special problems and comments
3.1 Precipitation			
Universal Rain Gages 6" traverse	8	Excellent	Records at some stations broken due to clock failure, accuracy during snowy and windy conditions questionable
Idaho Instruments Remote Snow Gage	2	Good	Electronic failure
3.2 Runoff/Streamflow/Groundwater			
Stevens A-35 records	4	Good-Fair	Ice in stilling wells, 4 spring drive clocks sometimes stick
3-ft H-flume with FW-1 recorder	1	Fair	Accuracy of record questioned when operated by "other than ARS" people
Supercritical flume with FW-1 recorder and stacom manometer	1	Fair	Fine mine spoil clogs up stilling well intake and confuses manometer, accuracy when carrying heavy sediment loads not known, effects of changes in upstream channel characterisitcs on flow rating not known
3.3 Sedimentation			
PS-69 automatic pumping samplers	3	Poor	Battery, electronic and pump failures
Chickasha automatic pumping sampler	2	Poor	Reliable unit, but intake problems with manometer triggering device, batteries frequently down, freezing problems
Isco portable pumping samplers	3	Excellent	Units are easy to move and program very reliable when properly cared for, quality of record not known on coarse material
3.4 Water Quality			
Chemical concentrations	14	Excellent-Good	Some locations dry up during the year - many other locations along the streams are sampled only after snowmelt each year

REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM THE SOUTHEAST WATERSHED RESEARCH LABORATORY

by

Laboratory Staff

INTRODUCTION

The Southeast Watershed Research Laboratory (SEWRL), located at Tifton, Georgia, consists of a resource management unit and an environmental quality unit. The laboratory also cooperates with the Florida Soil and Water Research Unit in watershed research at Ft. Pierce, Florida.

The mission of the SEWRL is to develop concepts of watershed stream performance based on an understanding of hydrologic, sediment, and chemical transport processes, and to develop methodologies for predicting and evaluating the impact of agricultural management practices on the environment and natural resources of the Southeast. Specific objectives of the program are:

(1) to quantify rainfall, streamflow, and ground water movement on complex-cover watersheds in the Southern Coastal Plain;

(2) to relate watershed hydrologic response to rainfall, stream network characteristics, land use and management, and internal hydrologic processes;

(3) to define and determine watershed internal chemical processes, and quantify the movement of sediment, nutrients, and pesticides within and from complex-cover watersheds;

(4) to develop prediction and mathematical relationships for use in analysis, simulation, and prediction of watershed hydrologic performance and watershed chemical processes; and,

(5) to evaluate and develop management techniques to maintain acceptable water quality and productivity of the soil and water resource base in complex-cover watersheds.

The SEWRL was established in 1966 by the Agricultural Research Service, with ongoing hydrologic data collection in Taylor Creek Watershed near Okeechobee, Florida, Indian River Farms Drainage District near Vero Beach, Florida, Monreve Ranch Watershed near Stuart, Florida, and Ahoskie Creek Watershed near Ahoskie, North Carolina. Little River Watershed (LRW) at Tifton, Georgia, was selected and instrumented for hydrologic data collection in the mid to late 1960's. This regional coverage provided a data base from Coastal Plains and Coastal Flatwoods land resource areas with which engineers and scientists could test regional methods for predicting storm runoff and water yield from ungaged complex watersheds.

Environmental concerns of the early 1970's resulted in the gradual development of a water quality research program by the SEWRL during the late 1970's. This program addresses sediment and agricultural chemical movement and watershed internal mineral and chemical processes. In addition to concentrations, measurements of precipitation and runoff enable the determination of sediment and chemical loads transported from the agricultural watersheds.

Streamflow measurement and water quality sampling are difficult in Coastal Plains and Coastal Flatwoods areas. Low gradient streams normally consist of relatively shallow flow over broad riparian zones rather than in well defined, incised channels. Woody vegetation in the riparian zone causes high retardance to flow, resulting in low velocities and large volumes of backwater. The sandy soils of the land resource areas have high infiltration rates, (Rawls, and others 1976) and much of the rainfall enters the soil and moves laterally and downslope over a subsurface impeding layer to become shallow subsurface return flow into the streams. This time delay along with low velocities in the riparian zones results in sluggish streams and poor basin drainage. However, the flow and vegetative conditions combine to provide a high degree of filtering of sediment and chemicals, which is difficult to evaluate.

Presently, the SEWRL data collection program is confined to the LRW and vicinity. Hydrologic and chemical processes are being studied at the watershed and plot scale. In addition, selected sites are being studied to quantify internal watershed processes. Data collection and chemical analysis on the Taylor Creek-Nubbin Slough Watershed located in Florida will be conducted by the South Florida Water Management District beginning October, 1981. Therefore, this report does not include Taylor Creek watersheds.

DATA ACQUISITION

2.1 Precipitation: Fifty-two digital raingages that record cumulative rainfall to the nearest tenth of an inch at 5-minute intervals were installed on and adjacent to Little River Watershed in 1967. Most of these gages have continued in operation since that time. Seven gages have been removed and 11 have been added at different times, bringing the present number in operation to 56. In addition to the digital recording gages, a standard gage is also maintained.

A summary of the precipitation data aquisition system along with problem situations and actions taken to deal with these problems is included in Table 1. A map of the early network, a brief description of data processing procedures, and general precipitation climatology are given in a previous report (Mills 1971).

2.2 Runoff/Streamflow/Groundwater: Special structures were designed to deal with problems associated with measurement of flow in low-gradient streams. These structures are referred to as horizontal broad-crested weirs with V-notch center sections. The wide horizontal sections give capacity for high flows, while the V-notch center section gives greater accuracy in the low to medium flow ranges. The broad-crested configuration reduces maintenance requirements while decreasing sensitivity to tailwater or backwater effects. Details on the design and construction of these structures may be found in Burford and Lillard (1963) and Yates (1974). Flow-measuring structures were installed in conjunction with highway bridges or culverts, the only points along the channels where flows could be confined with any degree of practicality.

Since construction, three weir crests have been raised because of submergence at low flows. Performance of structures generally has been satisfactory. Sediment accumulations above structures is minimal, and maintenance has been routine.

Model studies were conducted to determine optimum design criteria and head-discharge ratings for these structures. Flow-measurement structures proposed for LRW stations A and B were modeled at the ARS Water Conservation Structures Laboratory at Stillwater, Oklahoma (Gwinn, 1974). A typical broad-crested, V-notch center section and a scale model of the flow-measurement structure constructed at Station F were modeled by SEWRL personnel in the Soil and Water Laboratory of the Agricultural Engineering Center, University of Goergia, Athens, Georgia in 1967 and 1968

(Sheridan 1968; Williams 1973). A flow-measurement program conducted by trained personnel determined flow rates at all stations by use of timed-catch, and by wading and bridge current-meter measurements. Discharge ratings were subsequently developed for stations based on results of model studies and on field measurements.

Flow events to date have been of relatively short return intervals. Field measurements will be made when large events occur and discharge ratings will be revised as necessary.

Flow measurements on plot and mini-watershed areas have been made with H-type flumes and small (<0.5 feet) sharp-crested V-notch weirs. The flumes, ranging from 0.5 to 2.0 feet in depth, have been designed, constructed, and installed, according to Agricultural Handbook 224 (Brakensiek, Osborn, and Rawls 1979). Ratings for the H-flumes were obtained from Handbook 224. The sharp-crested V-notch weirs were rated by timed-catch measurements.

2.3 Sedimentation: Adequate collection of runoff and streamflow samples for sediment determination continues to be a problem at the SEWRL. Installation of automated pumping samplers has made it possible to obtain samples early in a storm period when technicians are unable to reach measuring stations quickly enough to obtain hand samples in off-duty hours. The problems encountered are: (1) sample representativeness of horizontal and vertical distributions of sediment, and (2) adequate sampling interval to characterize sediment transport throughout the storm runoff duration. Prior to installation of pumping samplers, infrequency of sampling was a major problem in computing sediment load.

Sediment transport in streamflow is not significant in Coastal Plain watersheds (>0.4mi^2) as reported by Sheridan, and others (1981a). Maximum concentrations of total solids during storm runoff have not exceeded 300-400 mg/l for the storms experienced in the record period (Sheridan, and others 1981b). Grassed and/or forested areas at the lower edges of hillside slopes are effective buffer strips that result in deposition of the sand and silt. Further filtering of runoff and streamflow occurs in the riparian vegetation through which the streams flow.

Streamflow samples are obtained with pumping samplers at five gaging stations. PS-69 samplers, with 12-hour sampling intervals, are used at gaging stations J, K, N, and O. An ISCO sampler, with a 12-hour sampling interval, is used at the gaging station for the urbanizing watershed UR. Sampler intakes at all five gaging stations are located upstream, directly in front of the weir notch, and fixed in elevation at notch level. The fixed intake does not provide integration of sampling either in the horizontal or vertical. Since sediment concentrations are low, samples from the fixed-point intakes are considered representative of the streamflow.

The PS-69 samplers and the ISCO sampler at gaging station UR are actuated by a switching mechanism to collect samples, at the 12-hour interval, at all times when streamflow stages are over the weir notch. Streamflow at these watersheds are prolonged, normally continuous from about November through July or August of the following year (Asmussen, and others (1975).

Samples of sediment-laden runoff from small watersheds (>5 acres drainage areas) currently are collected with ISCO pumping samplers equipped for variable sample size and variable time intervals. Pre-programmed sample size and sampling intervals were selected to provide good representation for the runoff events. Four sampling intervals were programmed at the factory to give graduated ranges of time increments for short, intermediate, and long-duration storms. A specific sequence is selected by the observer to be able to sample the storms characteristic of the particular

season. However, short-duration high-intensity storms may occur during any month of the year, and such a storm may occur when a relatively long duration storm is expected. Also, the automatic sampler starting switch is set at some arbitrary depth of flow, and some small, low-intensity storms may occur without samples being collected.

Runoff from the small watersheds is measured with H-type flumes. The pumping sampler intakes are located under the H-flume discharge nappe. The nappe flows into a concrete box with sufficient drain holes to provide continuous flushing of sediment, and at the same time provide good mixing and adequate volume for pumping. All small watersheds have grass channel approaches to the flumes. All coarse sands have deposited in the grass channels above the flumes. Samples collected from these small watersheds are also used for chemical analysis (see section 2.4). The sample data appear to be representative and adequate for accurate sediment and chemical load computations.

Surface runoff from small watersheds occurs during and shortly after rainfall events. Electronic water-level sensors, positioned at some pre-determined elevation, are located in the H-flume approach. The sensors are so positioned to prevent sampling the water from rainfall on the flume and approach floors.

2.4 Water Quality Parameters: Several studies of chemical transport and determination of selected water quality parameters conducted by the laboratory staff and cooperators have been published, eg. Jackson and others 1973; Asmussen, 1975; Asmussen and others 1975; White and others 1976; Asmussen and others 1977; Rohde and others 1980; Asmussen and others 1979. Other studies are currently underway. See Section 2.3 for discussion on small watersheds and plots. Many of these studies are short-term and data acquisition systems and procedures are designed to meet specific research objectives and therefore cannot be well categorized in simple format.

The SEWRL began joint research in nutrient cycling and transport in watershed ecosystems cooperatively with University of Georgia scientists in 1978. The study involves systematic streamflow and rainfall sampling for analysis of a number of elements and parameters as shown in Table 1. Sampling equipment and interval is discussed in Section 2.3. Selections for laboratory analysis are made from these samples based on stream stage and rainfall. Hand samples are collected at each station at weekly intervals for determination of organic carbon. Field measurements of dissolved oxygen and streamflow temperature are made also.

Studies of pesticide transport in streamflow from complex-cover watersheds are also underway. Difficulties and problems with compound identification and quantification at the very low levels encountered are currently being investigated. Procedures for determining very low levels of pesticides in groundwater are being investigated.

Table 1--Data acquisition system

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Watershed rain-gage network consisting of 56 digital gages	Evaporation	Oil used in gages
	Different cumulative rainfall amounts recorded due to temperature changes and wind when actual cumulative amount is mid-point between even tenths of an inch	Cumulative rainfall changes removed in processing when followed by a tenth inch decrease in cumulative recorded rainfall
	Timer failures	Improved timers installed
	Battery failures	Batteries changed on regular schedule before they become weak rather than rely on voltage check. Also, trace indicators removed to prevent battery drain
	Punch mechanism worn so that holes in tape indicating rainfall amount not punched clean	Punch mechanism replaced when problems occur. Bad data tape read visually and data entered individually on computer medium
	Areal representation of point measurements	Gages spaced more closely (1.5 miles) on small watersheds than on larger watersheds (3.0 miles). Closer spacing on a portion of the network provides informaiton on rainfall spatial patterns which can be used in interpolating between wider spaced sampling points

Table 1--Data acquisition system--Continued

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Digital gages at unit-source experimental sites	(Same as network gages with exception of areal representation problem)	
Standard non-recording raingage	Only daily amounts recorded	Used as index station only
2.2 Runoff/Streamflow/Groundwater:		
Streamflow measurement controls/ digital stage recorders	Low gradient systems	Horizontal broad-crested weirs with v-notch center section designed for use in low gradient stream systems
	Broad floodplains	Controls installed in conjunction with highway bridges or culverts where flows are confined
	Frequent submergence	Controls raised as necessary
	Recorder Mechanical/battery failure	Frequent servicing and maintenance with dual digital recorders and one chart recorder for back-up data
Plot/small watershed/ with H-flumes and v-notch	Insufficient data to define short duration events	Continuous chart recorders and digital stage recorders installed
Groundwater well network	Insufficient data (Weekly measurement)	Digital recorders installed (1-hour intervals)

Table 1--Data acquisition system--Continued

Instrument description	Problem situations	Action taken to insure data quality
2.3 Sedimentation:		
Suspended sediment sampling	Inadequate data from hand and single-stage samplers	Automatic pumping samplers installed
	Pumping sampler failures. (Start switch contacts too wide for runoff water ion content--ISCO samplers)	Closed contact gaps
	Correlations of sample time with digital gage record	Installed analog gage with sample time marker
	Sediment content of sample too small to determine particle size	Composited samples for particle size determinations

Table 1-- Data acquisition system--Continued

Instrument description	Problem situations	Action taken to insure data quality
2.4 Water quality parameters		
Streamflow samplers	Mechanical failures	Maintain routine servicing schedule
Rainfall Samplers	Possibly some contamination from wind blown dust	Install standard wet-dry samplers when resources are available
Auto-analyzers (NO_3-N, NH_4-N, PO_4-P, SO_4-S, total N, total-P, total-C, Cl^-)	Mechanical and electronic failures common to type of equipment	Laboratory staff maintains rigorous quality control and instrument checks
Atomic absorption spectrophotometer (Ca, Mg, Na, K)	same	same
Conductivity meters, pH meters, other electrometric methods; (pH, conductivity, dissolved oxygen)	same	same
Gas chromatographs; (pesticides)	same	Rigorous quality control procedures; Equipment under service and maintanence contract
High performance liquid chromatograph (pesticides)	same	same
Gas chromatograph/Mass Spectrophotometer (pesticides)	same	same

DATA QUALITY

3.1 Precipitation: Evaluation of precipitation data quality is summarized in Table 2. Precipitation data quality problems are largely related to recording accuracy, time interval of sampling, and estimation of data when gages malfunction. Since the digital gages only record cumulative rainfall to the nearest tenth of an inch at 5-minute intervals, computed short duration intensities contain quite a bit of uncertainty. However, for long duration storms and high intensities the error is decreased. The error in intensity is probably not significant for large watersheds, but may be important for plots and unit source areas.

The data quality problem related to estimation of data when gages malfunction can be handled by using all available information for the estimations and reducing the total time of malfunctions. The percentage of record requiring estimation has been larger since about 1975. This is probably due to the decreased frequency of gage visits from weekly to biweekly. The change in frequency of visits was a result of an administrative decision to reduce vehicle mileage and personnel. For the period 1968-80, the percentage of record that must be estimated varies by gage from 0.5 percent to 13.2 percent.

3.2 Runoff/Streamflow/Groundwater: Flow measurement devices used by SEWRL on LRW have generally functioned as designed. Structural problems are minimal; controls are relatively self-cleaning of vegetative debris, and the low sediment presence in streamflow does not lead to significant sediment buildup behind the control. Recorder or instrumentation problems (timer malfunctions and discharged batteries) have been dealt with by frequent servicing and field checks. Missing stage data are minimized, if not essentially eliminated by the presence of 2 digital and 1 chart recorder at each major structure. Recorder stage readings are tied in to mean sea level elevation benchmarks at each location and the recorder reference points as well as structure inverts are resurveyed periodically to assure proper recorded stage values and zero flow elevations.

3.3 Sedimentation: Problems associated with sediment concentration determinations are those of inadequate representation in time and location of sample collection.

Sampler failure during storm periods results in incomplete records. Source runoff and erosion from upland areas may occur in one or two major storms during a year. Sampler failure during these storms results in loss of much of the record for the entire year.

Laboratory analysis of samples is a problem, also, since concentrations are generally low. The small volume samples are used for both sediment and chemical analyses. Total sediment concentrations are being determined when processing for chemical analyses. However, sediment particle size analysis without compositing samples is practically impossible due to the small quantities. Particle size distribution is important in the development and testing of physically based models such as CREAMS (Knisel 1980).

3.4 Water Quality Parameters: The quality of most of the determinations are good to excellent since well validated analytical procedures are used. However, data quality in the context of its usefulness depends on the completeness and extent of the data base. Some difficulty always exists in converting data from point samples to chemical mass in streamflow, but compromises are necessary between numbers of samples and laboratory capacity.

Systematic, long-term water quality and chemical transport studies comparable to traditional hydrologic studies whereby continuous input-storage-output records are maintained have not been conducted because of past priorities and resource limitations. Resource limitations will likely continue and possibly have an adverse impact on data quality in the above context. The water quality program in the SEWRL has suffered as in most watershed programs from the fact that it was add-on research, at times over-extending existing resources. Only recently with increased funding has the SEWRL had opportunities to make significant improvement in its water quality program.

Research on nutrient cycling in watersheds conducted jointly between USDA-ARS and the University of Georgia has dramatically improved the water quality data base. However, since this project is funded by a grant from the National Science Foundation, its continuation as a long-term project is uncertain. Should these funds no longer be available, significant re-adjustments will occur in the SEWRL program.

Table 2--Data quality evaluation

Description of current stations	Number of stations	Estimate of data quality[1]	Special problems and comments
3.1 Precipitation:			
Digital Recording gages	56	Good	A portion of the record must be estimated because of gage malfunctions.
Standard non-reading gage	1	Good	Only daily amounts recorded.
3.2 Runoff/Streamflow/ Groundwater:			
Horizontal broad crested weirs/ v-notch section/ digital recorders	6	Low-flow rates-Good to Excellent, based on timed-volume catches	See Table 1 for problem situations and actions taken.
Horizontal weirs/ v-notch section/ angle iron crests/ digital recorders	3	Moderate to High flows-Fair to Good, based on wading and bridge current meter measurements	same
H-flume/chart recorders	8	Good - Excellent	same
90° v-notch weir/ chart recorders	1	Good - Excellent	same
Groundwater well/ digital recorders	3	Good - Excellent	same
3.3 Sedimentation:			
PS-69 automatic pumping samplers	4	Good	Point sample intake location; mechanical/electrical failure; low sediment concentrations.
ISCO portable pumping samplers (variable sample interval)	6	Variable	Low sediment concentrations; Electronic failures.
ISCO portable pumping sampler (fixed sample interval)	1	Good	Low sediment concentration; battery/ electronic failures; point sample intake above weir.

Table 2--Data quality evaluation--Continued

Description current stations	Number of stations	Estimate of data quality	Special problems and comments
3.4 Water Quality Parameters			
PS-69 automatic pumping samplers	4	Good - Excellent	Sediment and sediment-borne chemicals very low and large-volume samples would be required for adequate analysis.
ISCO portable pumping samplers (variable sample interval)	6	Variable	Low sediment concentrations; Electronic failures.
ISCO portable pumping sampler fixed sample interval	1	Good	Low sediment concentration; battery/ electronic failures; point sample intake above weir.
Rainfall samplers	3	Good - Fair	Some possible contamination due to wind-blown dust.
Manual Samples	Variable	Good - Fair	Difficult to obtain at desirable times during storm events.

1/ Excellent: ± 5%
Good : ± 10%
Fair : ± 20%
Poor : > 20%

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

It is anticipated that soil and water resource demands will increase in the next decade because of increased food demand. To meet this need presently available data bases, parameters observed, instrumentation available, and sites observed must be critically evaluated. Past watershed research has emphasized input and output studies with less emphasis on internal processes. As interest changes to internal processes new concepts in instrumentation, data recording systems, and sampling techniques are needed.

In the past, data needs for watershed hydrologic and environmental quality model development and testing have not been satisfactorily defined in relation to long-term national priorities. When these priorities are established they will dictate equipment, techniques, and instrumentation necessary to describe watershed physical conditions, chemical processes, and environmental processes. Presently, there is limited automatic equipment available for sampling surface and subsurface water for determination of chemical constituents. In addition, techniques for relating surface and subsurface flow paths and chemical movement have not been developed.

Specific equipment needs include: (1) magnetic-tape recording stage and raingage equipment to replace chart and punch tape instruments; (2) better rechargeable battery systems to replace current systems; (3) water sampling equipment that can be programmed to change sample volume, change sample timing, take continuous or point samples over long periods of time with multiple events occuring; (4) groundwater sampling equipment to sample vertical and lateral moving water; (5) better water quality instrumentation which will continuously observe selected parameters and record observations on magnetic tape at remote field locations and; (6) develop automated mapping equipment which is computer compatible to describe vegetation, soils, and geologic parameters for model input.

Watershed water quality instrumentation research in the past has received limited attention. It is recommended that research in water quality be supported with a long-term commitment such that new and existing methods and instrumentation can be properly evaluated.

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REPORT ON QUALITY OF PLOT AND SMALL WATERSHED HYDROLOGIC DATA FROM THE SOUTHERN PIEDMONT CONSERVATION RESEARCH CENTER

A. W. Thomas and G. W. Langdale

INTRODUCTION

The mission of the Research Center is to develop wise, efficient, economical, and effective agricultural uses of the natural resources of soil, water, plants, and climate in the Southern Piedmont physiographic resource area of the southeastern U.S. This area extends from Virginia southwestward through the Carolinas, Georgia, and into Alabama and contains approximately 38 million acres. The soils are classified primarily as Udults and exist in the Udic moisture regime (>40 inches mean annual precipitation and <5 inches of absolute water deficit) and the thermic temperature regime (59° to 72°F mean annual soil temperature at 20 inch depth).

The Center was established in 1937 by the Soil Conservation Service as a field research location with 981 acres to study soil and water conservation problems. At that time the major concern was severe erosion on row-crop agriculture. The primary objectives, for which the hydrologic data described in this report as used presently, include:

(1) to elucidate the transport systems of water, sediments, and agricultural chemicals through the landscape on agricultural lands and develop predictive capability to provide a rational base for prescribing land management and conservation practices, and

(2) to develop land management practices and technologies (including surface water structures, cropping systems, tillage and crop residues) that maintain optimum crop production, conserve soil and water resources, minimize nonpoint source pollution and are compatible with modern farming techniques and machinery.

Most research scientists at the Center are engaged in field and plot research programs that include animals, pastures, and row crops. They require precipitation data. Generally, the raingage network on location is adequate for their needs, but when not, gages are installed for the duration of their special need. We have learned that from the thunderstorms which provide most of the rainfall during the summer growing season, a raingage must be in close proximity of study area.

Since the late 30's local scientists have been engaged in evaluating rainfall and runoff characteristics of a small watershed under various agricultural management systems. The 19-acre gaged area was primarily in row crops during the 40's and 50's but more recently in grazed pasture. During the 70's, material transport under different conservation and cropping systems became the major interest. Four watersheds ranging in size from 3 to 7 acres were instrumented to continuously measure sediments and certain agricultural chemicals associated with storm runoff. These small watersheds continue to be monitored and provide the basis for the runoff, sediment, and chemical sections of this report.

DATA ACQUISITION PROGRAM

2.1 Precipitation: The 96-year average precipitation for Watkinsville is 49.71 inches with March and October having the highest and lowest monthly average of 5.41 and 2.98 inches, respectively. The rainfall characteristics of the area range from air mass thunderstorms that produce considerable rain in short periods, to slow moving

frontal systems that produce gentle rain for days. One gage can adequately represent large areas during these rain producing frontal systems. However, problems do exist in adequate representation for many of the localized thunderstorms. There have been observations where much more rain fell on a 7 acre watershed than was measured in the raingage stationed on the perimeter of the area. Because of these observations, we believe that gages must be very near research sites for accurate measurements.

Due to the necessity of accurate rainfall data on the small watersheds, maintenance of the gages is performed thrice weekly and other times when rain is expected. The frequent visits provide for accurate and complete data from the weighing gages. In addition a standard non-recording gage is adjacent to each recording gage, and during data processing the weighing gage total is adjusted to the standard total.

The Center also serves as an official precipitation station for the U.S. Weather Bureau. We maintain the station, keep records and file reports as required. A representative routinely checks the gages and monitors the program.

2.2 Runoff: The runoff instrumentation described in this report is not associated with streams, but the devices are placed at natural drainage point or drainageways on the small watersheds. Therefore, runoff occurs only during storms and for relatively short periods following rain. To concentrate runoff through the weir and flumes, dikes were constructed on each side of the devices. The 19-acre watershed is gaged with a concrete broad-crested 2 to 1 V-notch weir. The stage of the weir is measured with a FW-1 recorder. Carreker and Barnett (1953) described the details of the gaging site and station. Standard type H-flumes (2.5 feet in height), approaches and sloping bottoms, constructed from 14-gauge stainless steel according to Agricultural Handbook 224 (1962) specifications, were installed at each of the four smaller watersheds. The stages for the flumes are measured with FW-1 recorders. Smith et al. (1978) show pictures and provide further details of the instrumentation.

To ensure complete and accurate records, the instruments are checked twice weekly and frequently before and/or during storm events. One of the critical elements is to ensure that the clocks of the raingages and FW-1 recorders are synchronized. The response of runoff to intense burst of rain is very rapid in the small areas. Twice very large and intense storms have caused runoff in excess of the capacity of the flume on the 7-acre area. High water marks on the dike were used to make estimates of the runoff in addition to that through the flume.

2.3 Sediment Transport: Instrumentation was designed to automatically and continuously sample runoff from the four H-flumes for sediment concentration and total load analyses. The flumes were built with 1-on-8 sloping false floor and matching approach section to reduce silting within the flume. Continuous runoff sampling was achieved with a motorized sampling slot traversing through the flume discharge. The design permitted a greater proportion of the runoff to be collected at low flows than high flows. The samples flowed to a sequential collector housed in a refrigerated compartment. The collector was capable of taking fourteen 11-liter samples. A modified FW-1 recorder was used as an event marker to indicate the time at which each sample was acquired. The entire sampling system was powered by direct current from an AC/DC converter and storage batteries to ensure operation in the event of temporary power outages during thunderstorms.

The sediment concentrations varied tremendously due to condition of watersheds and nature of storms. Intense storms following tilled soils moved large amounts of soil through the flumes. The runoff was nearly as clear as drinking water during conservation tillage systems. Also, the number of runoff samples for different storms varied considerably.

On site inspection was required to ensure adequate data during large storm

events. In addition to the recorders discussed in the "runoff section", the motorized collector system required maintenance. If more than fourteen samples were collected, it was necessary to replace full containers with empty ones. Some large storms produced approximately forty samples. Removing trash from the divider slots was also necessary to maintain proportionate sampling.

2.4 Chemical Transport: The transport of dissolved and absorbed agricultural chemicals from the four small watersheds has been closely associated with the methodology under the sediment transport section. The specific chemicals that have been analyzed include: TKN, NH_4-N, NO_3-N, total P (total dissolved P and sediment P), PO_4-P, and Cl. Herbicides measured in runoff include: diphenamid, paraquat, trifluralin atrazine, cyanazine, and 2,4-D. The samples for chemical analyses were in contact only with stainless steel from the entrance at the flume till it reached the laboratory. The compartment housing the samples was maintained at 4°C by a forced-air refrigeration system. Since the refrigeration unit did not have a backup power system, it was necessary to move the samples immediately to the laboratory after power failure from thunderstorms. Within a few hours after collecting samples it was normal to have them moved to the laboratory, particularly in cases of recent field application of chemicals. Smith et al. (1978) discuss laboratory procedures, analyses and interpretations of samples.

Devices were constructed to collect rainfall samples for nutrient analyses. The collection system was protected from contamination with an aluminum cover that was removed automatically during rainfall. The driving motor was energized by a change in resistance of a sensor during rainfall. This equipment required very little maintenance.

DATA QUALITY ANALYSIS

3.1 Precipitation: Since at Watkinsville there are no watersheds with more than one raingage measuring precipitation, we do not have a problem with synchronization of clock time for different raingages. Our data quality difficulties are minor maintenance of gages such as stopped clocks and calibration of weighing gages. For this reason we visit gages thrice weekly and more often when precipitation is expected or actually occurs. Calibration problems are easily detected from comparison of adjacent standard non-recording gage. Infrequent problems are caused by animal disturbance of gages and vandalism. There have been a few observed freak storms where the gage obviously did not receive the same amount of rain as most of the watershed. In our modeling activities of rainfall-runoff relationships we have suspected that in certain cases the measured rainfall did not represent the actual amount received on watershed. These inadequacies are difficult to correct. In other cases where the clock stopped, intensity patterns have been satisfactorily determined from the total rainfall in the standard non-recording gage and rainfall distribution pattern from a nearby gage.

3.2 Runoff: The broad-crested V-notch weir gaging the 19-acre watershed was installed in the late 30's by the research arm of the Soil Conservation Service. The design and installation precisely followed standards developed by D. B. Krimgold, civil engineer, of SCS. He also developed field calibration for the weir which was used by those utilizing this design. The weir measures accurately low flows and structurally can handle large flows. This weir has very rarely measured more than half of the maximum 3.5-foot stage. An accurate ponding correction was developed for the calibration to account for ponding influences. Surveys have been made many times since installation to ascertain the appropriateness of the ponding correction. The approach to the weir has been in sod and is fairly uniform except for winter and summer differences.

The major difficulty with the runoff data is clock differences in rainfall and weir flow. Since the response time on small watersheds does not vary significantly

Table 1. Watkinsville Hydrologic Data Acquisition Systems

Instrument Description	Problem Situation	Action Taken to Insure Data Quality
2.1 Precipitation:		
Standard non-recording raingage	Need standard measurement	All standard procedures followed.
Weighing-type raingage (Standard gage at each site)	Evaporation	Field trip for resetting gage immediately after rainfall.
	Ice	Catch is melted and measured.
	Clock failure	Gages checked thrice weekly and/or before anticipated rain.
	Calibration problems	Weather station gages calibrated each 6 months and others when problems are encountered.
	Site selection	Sites selected where research needs for rainfall data are greatest.
2.2 Runoff:		
V-notch weir	Recorder failure	Recorder checked twice weekly and/or before anticipated rain.
	Runoff accuracy	Standard design and precision construction. Used ponding correction.
	Sediment deposition on weir approach	Large ponding area for trapping. Deposition removed as necessary. Watershed in pasture since 50's.
Type H-flumes	Recorder failure	Recorder checked twice weekly and/or before anticipated rain.
	Sediment deposition in weir approach	1-on-8 sloping false floor and matching approach section to minimize problem.
2.3 Sediment Transport:		
Sediment concentrations and load	Inadequate data from hand samples	Motorized traversing slot to sample portion of runoff.
	Sample time	Event marker on separate recorder.
	Representative samples from event	A maximum of 14 samples were possible without manual involvement.
	Instrumentation failure	On site inspection during major storms. A backup power system was used.
2.4 Chemical Transport:		
Chemical concentrations and load	Sample contamination	Stainless steel flumes and sampling system.
	Sample preservation	Sample caught in refrigerated compartment at 4°C. Samples moved to laboratory within hours of collection.
	Representative samples from event	A maximum of 14 samples were possible without manual involvement.
	Instrumentation failure	On site inspection during major storms. A backup power system was used.

we have attempted to determine problems and make judgmental corrections. Our frequent maintenance schedule minimizes this problem.

The four type H-flumes were precisely constructed and installed according to Agricultural Handbook 224 (1962). The approaches to these flumes have been in sod with major variation in vegetative conditions of winter and summer. As with the weir the major difficulties are associated with synchronization of rainfall and runoff events and maintenance of flumes. In data analysis, efforts have been made on all storms to consider inconsistencies with time. Modeling activities by Bruce et al. (1975) and Thomas et al. (1981) have evaluated rainfall-runoff characteristics on these small watersheds. The simulation activities indicated consistent data.

3.3 Sediment Transport: With the motorized sampling slot traversing through the flume discharge, the entire nappe is sampled for sediments. With this procedure sampling points are not as critical. The time required to accumulate discrete samples depends on the weir stage or the nature of the hydrograph. The sampler collected about 0.002 of the total flow at low stages (0 to 5 cm) and about 0.0004 of the total flow at higher stages (45 to 50 cm). This design ensured adequate sampling at low flows or small events and a reasonable number of samples for larger events. From each sample the average sediment concentration for the discharge during the sampling time was determined. The total sediment load was integrated by multiplying each sediment concentration by the proportionate discharge. We believe that it is difficult to get a better estimate of total load without measuring all the sediment leaving the watershed.

For the past few years, instead of collecting multiple samples we have taken one sample per storm for sediment analysis. The accuracy of total load is less, however, we believe it is adequate for present studies. Maintenance is much less for this sampling level.

The sediment data described in this section have been used extensively and intensively in many modeling activities. Presently the CREAMS effort (Knisel, 1980) is using this data. The data is probably some of the best watershed sediment information available.

3.4 Chemical Transport: The sampling for chemical constituents was made as described under the sediment transport section. The samples were stored in a refrigerated compartment in the field and generally moved to the laboratory within a few hours. In the laboratory the approximate 11 liter sample was subdivided into three samples with a splitter described by Fleming and Leonard (1973). The sub-samples were stored at 4°C for further processing by various laboratories. Laboratory techniques for analyses and results are reported by Smith et al. (1978).

As with sediment sampling, we believe that a representative sample was acquired from the runoff event. We also believe that the following precautions added integrity to the results: (1) stainless steel flume and sampling equipment, (2) refrigeration in the field, (3) samples moved to the laboratory in a matter of hours after collected, (4) refrigeration in laboratory, and (5) analyses in laboratory quickly as possible. Even with the great deal of care exercised in these studies, there are limitations in field chemical transport studies. However, these studies represent about as much effort that can be reasonably expected in field studies of this magnitude.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

It is time to take a new innovative look at instrumentation for measuring precipitation and water stage. After using digital instruments under different conditions,

we have returned to analog instruments with wind-up clocks. Both systems are subject to malfunctions; however, with the charts much more information is normally available when problems do occur. We have especially found this to be true when one is concerned about synchronous time in simulating runoff from given precipitation patterns on small watersheds.

Develop instrumentation for monitoring water levels in deep and shallow wells. The instrumentation should operate within very small access tubes. At Watkinsville we have several years of experience with developing an instrument for monitoring shallow water tables (Lovell, 1978). We have made progress but many problems have plagued the quality of data that we hoped to achieve.

Develop better techniques or information concerning sediment and chemical sampling from runoff. We find that we are assuming quite a bit in sampling and computing total loads of transported materials. For example, we need to know more about how representative is the sampling from the traversing slot sampler. We need to develop criteria to judge whether sampling errors are relatively insignificant or whether these errors might alter our conclusions or recommendations.

The technology is available to develop central recording of hydrologic data. Each research group could develop its individual system; however, it seems appropriate to develop basic packages of instrumentation that could be extended to meet different needs.

Much of the modern instrumentation used in the field today is quite vulnerable to lightning. These problems can be expensive as well as frustrating. Any new developments of instrumentation need to consider this hazard.

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Table 2. Watkinsville Hydrologic Data Quality Evaluations

Description of Current Stations	Number of Stations	Estimate of Data Quality	Special Problems and Comments
3.1 Precipitation:			
Standard non-recording raingage.	7	Excellent	Evaporation during hot season is the major problem.
Weighing-type raingage (2 at one site)	8	Good	Totals are adjusted to standard values.
3.2 Runoff:			
V-notch weir	1	Good	Low maintenance, stage recorder must function, continuous record since 1939.
Type H-flume	4	Good	Low maintenance, stage recorder must function.
3.3 Sediment Transport:			
Runoff splitter and sample collector	4	Good	Requires frequent maintenance and on site during large events.
3.4 Chemical Transport:			
Runoff splitter and sample collector	4	Good	Requires frequent maintenance and on site during large events.

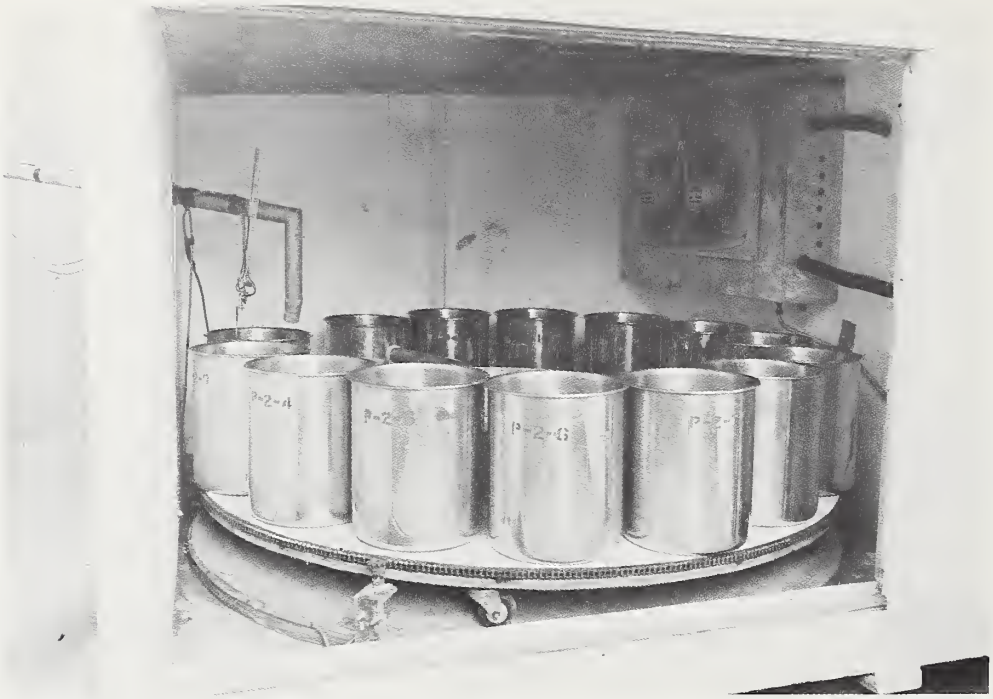

Figure 1. H-type flume with sampling equipment in rear of one of four small watersheds.

Figure 2. Sequential runoff sampler collector in refrigerated compartment at one of four small watersheds.

REPORT ON QUALITY OF WATERSHED DATA FROM THE HAWAII SMALL WATERSHED PROJECT[1/]

Keith R. Cooley[2/]

INTRODUCTION

In Hawaii, as in humid tropics generally, despite the relatively low susceptibility of highly weathered soils to erosion, the magnitude of soil loss is generally acknowledged to be far greater than in temperate regions (Hudson, 1971). This has been attributed to a combination of climatic extremes, steepness of topography, and inadequate precautions taken during agricultural or urban development; however, data to confirm or refute Hawaiian soil loss estimates are scarce. Such data are essential for an accurate definition of the amount of agricultural erosion, as it is often site specific. The concern over erosion, and its source, was intensified in Hawaii when soil sediments were found deposited on coral reefs surrounding the islands and on the oyster beds in Pearl Harbor.

This study was conducted in cooperation with the University of Hawaii between 1971 and 1979 on six, small, cropped watersheds on representative residual and volcanic ash soils in Hawaii (El-Swaify and Cooley, 1980; Frasier et al., 1976). Two of these watersheds, which are planted to sugarcane, are on the island of Hawaii. The other four, of which one is in sugarcane, two are in pineapple, and the fourth has been planted to both crops, are on the island of Oahu. Data collection, consisting of rainfall, runoff, sediment, and field conditions, such as tillage operations or crop stage, started in early 1972 on all of the watersheds, except one pineapple site. That site was instrumented later, and data collection started at the beginning of 1975.

1.1 Study Objectives:

a - To determine the magnitudes of soil losses caused by natural erosive rainstorms under existing cultural practices associated with sugarcane and pineapple production.

b - To develop relationships between rainfall erosivity, runoff, soil erodibility, land management, and crop cover on observed soil losses.

1.2 Instrumentation: Critical depth flumes with waterstage recorders were used to provide a continuous record of the runoff from the watersheds. Precipitation was measured with recording raingages located on or adjacent to each watershed. A proportionate sample of the runoff water was collected for sediment analysis with specially designed and calibrated sediment samplers at the outlet of each flume. A photo of the critical depth flume and the sampling equipment at the outlet of one of the pineapple sites is presented in Figure 1.

1/ Contribution from the Agricultural Research Service, USDA. Work partially supported by the University of Hawaii, Honolulu, Hawaii under Cooperative Agreement No. 12-14-5001-320.

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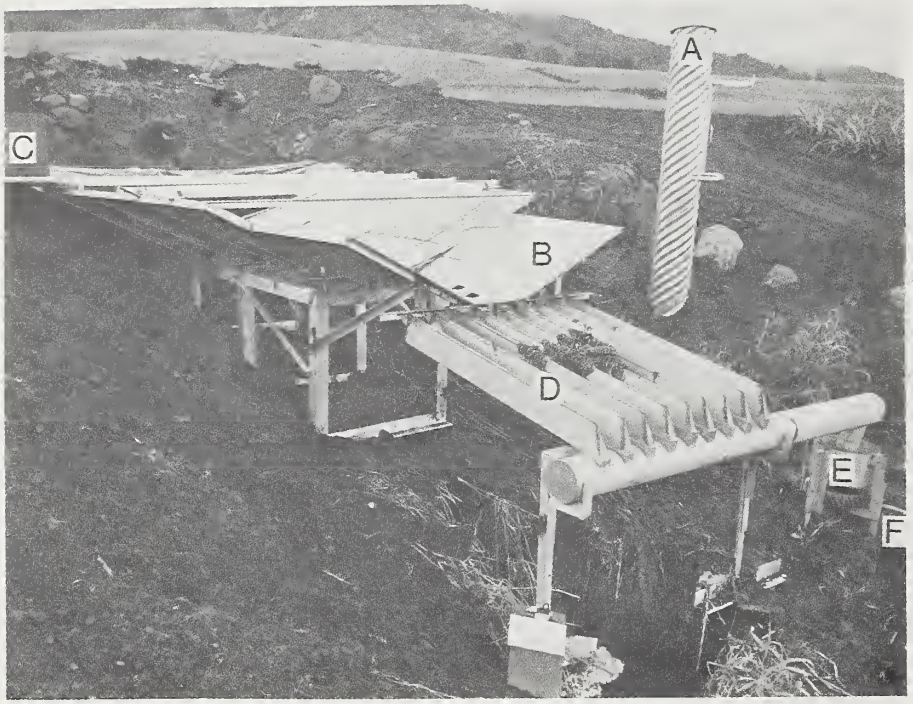

Figure 1. Instrumentation for rainfall and runoff monitoring and for sediment splitting and collection: A, tower containing raingage; B, critical depth flume; C, recorder; D, sediment splitter; E, second (rotation) splitter; and F, tube leading to collection container.

DATA ACQUISITION PROGRAM

2.1 Precipitation: Precipitation in Hawaii is extremely variable, ranging from less than 10 inches to over 400 inches annually within a few miles. The predominate weather pattern consists of trade wind moisture orographically lifted by the island mountains, producing showers almost everyday in some areas. Frontal storms also occur and, when combined with the trade wind storms, produce large amounts of precipitation in rather short periods.

Locating raingages to obtain representative areal coverage was a problem due to total cultivation in farmed areas and the dense growth of trees in bordering undisturbed areas. Since the watersheds were small (1 to 7 acres), and it was difficult to obtain installation approval for most desirable locations, only one gage was installed at each site. In some cases, catch could be affected by storm direction, by tall vegetative cover, or by elevation differences between the gage site and the watershed, due to the straitified nature of trade wind storms.

Problems were encountered with both Fischer-Porter punch tape and Leopold-Stevens continuous chart types of recording instruments used, but more data was collected using the Leopold-Stevens equipment (Table 1). The lack of a trained maintenance and repair technician was more critical when the Fischer-Porter equipment was in use. When set to punch or record every 5 minutes, down-time of the Fischer-Porter recorders was as high as 40 percent at some sites. The equipment failures were generally caused by punch problems, excessive friction in the gears, or loss of battery power. The major problem with the continous recording Leopold-Stevens equipment, which replaced the worn-out Fischer Porter equipment, occurred during long (12 to 36 hour) duration storms. Even though the rainfall was mostly of low intensity, the total precipitation of 4 - 20 inches during the storms would actuate the tipping bucket mechanism numerous times and discharge the batteries so that the solenoid would not trip and the record was lost. Later in the storm, after minor recovery, the batteries would sometimes have sufficient power to function properly.

2.2 Runoff: Runoff from all of the study watersheds was ephemeral; that is, it occurred only after periods of prolonged or high intensity rainfall. Stream channels were not well defined in most cases, but were merely depressions, and were included in normal field tillage operations.

The runoff was influenced considerably by the percent of watershed area occupied by roads. The percentage of area in roads varied from zero for some sugarcane sites to almost 20 percent for one pineapple site. Observations indicated that these field roads not only contributed to runoff, but also added appreciably to the sediment load because of the loose material caused by traffic.

The biggest problem associated with the measurement of runoff was caused by the sediment carried by large or high intensity storms (Table 1). This was particularly a problem immediately after harvest or tillage operations when the fields were bare. Once the crops became established and covered more than 80 percent of the surface area, runoff was either limited to that produced by the roads, or contained only suspended sediments. Under good cover conditions, loss of data was more often caused by mechanical failure of the recording system than by flume or sediment problems.

Fischer-Porter punch tape and Leopold-Stevens continuous chart types of water stage recorders presented some problems, but again the Leopold-Stevens seemed to require less technically trained technicians, and provided more useable data.

2.3 Sedimentation:

Sediment, as usual, was the most difficult to measure. Although a theoretical analysis and laboratory tests showed that the sampling system used provided an accurate aliquot of water, suspended sediment, and bedload material, many problems were encountered. The problems included:

a - Plugging of the splitter slots by aggregated particles larger than the design width;

b - Inundation of the rotating sampler caused by high concentrations of sediment, especially at relatively flat sites where the rotating sampler was placed in a hole;

c - Overfilling or floating of the collection barrel caused by large runoff events;

d - Inundation of the entire sampling system by crop debris immediately after harvest and tillage operation that coincided with large, high intensity storm events.

Table 1. Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
A - Fischer-Porter weighing raingage recording every 5 minutes on punched tape	a - Malfunction of automatic siphon	a - Reset and clean
	b - Battery failure	b - Replace
	c - Punch block jams	c - Clean punch block
	d - Electronic timer failure	d - New timers
	e - Overpunching on tape	e - Clean punch block and gear drives
	f - Mechanical failure of wires or gears	f - Replace
B - Leopold-Stevens tipping bucket continuous chart recording raingage	a - Deficient catch	a - Volume collection as a check
	b - Battery failure	b - Scheduled checks and replacement
	c - Clock failures	c - Scheduled cleaning, etc.
	d - Evaporation	d - Bucket vs. volume relation; silver paint & shielding
	e - Mechanical problems (ink, solenoid, switches, etc.)	e - Regular cleaning, lubrication, and maintenance
2.2 Runoff:		
A - Critical depth flumes with water stage recorders	a - Sediment deposition in flume	a - Modified flume
B - Fischer-Porter punch tape recorders	a - Punch block jams	a - Routine cleaning
	b - Battery failure	b - New batteries
	c - Overpunching	c - Cleaning
	d - Mechanical failures	d - Routine inspection, etc.
C - Leopold-Stevens continuous chart recorders	a - Mechanical failure	a - Routine inspection, etc.
	b - Clock failures	b - Replaced
2.3 Sedimentation:		
A - Fixed slotted splitter [modified Barnes & Frevert (Barnes and Frevert, 1954)]	a - Occasional plugging	a - Routine cleaning
	b - Questionable accuracy during low flows	b - Flow guide blocks
B - Rotating slotted sampler [modified Coshocton wheel (Parsons, 1955; Replogle and Johnson, 1963; Wang et al., 1971)]	a - Occasional plugging	a - Routine cleaning
C - Sample collection barrel	a - Overfilling	a - None
	b - Floating out of hole	b - Rope tie downs installed

DATA QUALITY PROBLEMS

3.1 Precipitation: Considerable loss of data at some sites, caused by failures of the Fischer-Porter raingages, obviously makes monthly and annual totals deficient. However, the storm data collected are considered to be of good quality (Table 2).

An inherent problem with tipping bucket systems, such as the Leopold-Stevens equipment used, is encountered during high intensity rains when the bucket simply does not tip fast enough, causing splash and spillage, and, therefore, undercount of the actual rainfall. This problem was partially rectified by catching the total volume of rain below the tipping bucket, producing monthly and annual totals, and improving overall data quality.

3.2 Runoff: Since both sugarcane and pineapple crops provide a dense cover for long periods between tillage operations, bare or limited cover conditions exist for only a small portion of the complete cropping cycle. Therefore, potential for high sediment loss is also limited to a small percentage of the time, and most of the runoff data is obtained under low sediment concentration conditions and is of excellent quality. However, as noted for the raingages, recorder failures did occur; thus causing a loss of some records. Occasional high sediment loads, and deposits of sediment in the flume itself caused measurement problems and reduction in the quality of data as noted in Table 2.

3.3 Sedimentation: Most of the water collected from the sampling system was essentially clear. The main sampling problems were encountered during very low flows (and, therefore, very little sediment carrying capacity) when the water would miss the slot or fail to turn the rotating wheel, or from very high flows when the rotating wheel and/or the collection barrel would be inundated (Table 2).

RECOMMENDATIONS

Regardless of the type of recording equipment used, it is important, in order to obtain quality data, to make a commitment to have trained technicians who will be with the project for a long time, and who understand both the equipment and the hydrologic processes being recorded. Regularly scheduled site visits and maintenance, such as changing batteries or cleaning clocks, should also be established.

4.1 Precipitation: The Leopold-Stevens strip chart recorders provided more useable data with less maintenance and technician training than did the punch type Fischer-Porter recorders. A quick look at the chart immediately after removal can provide an indication of problems that can then be corrected before the next visit. Since both rainfall and runoff are recorded on the same chart with the Leopold-Stevens equipment, synchronization of time is not a problem; however, the Fischer-Porter equipment uses separate punch mechanisms and time differences of $\pm$ 5 minutes were possible.

Battery problems can be reduced by placing batteries in a vertical position rather than horizontal.

4.2 Runoff: The strip chart type recorder again provides more information in an easily understandable form than the punch type equipment.

There still exists a critical need for a flume that will provide accurate runoff measurements, will work under high sediment concentrations, and will resist sediment deposits in the measurement section.

4.3 Sedimentation: Vertical slot traversing samplers powered by solar cell charged batteries, and other newer sediment sampling schemes, are preferable to the system

Table 2. Data Quality Evaluation

Description of current stations	Number of stations	Estimate of data quality	Special problems and comments
3.1 Precipitation:			
A - Fischer-Porter recording gages	5	Good	Considerable missing data due to various failures
B - Leopold-Stevens	6	Good to Excellent	Record deficient for high intensity storms but volume available for total
3.2 Runoff:			
A - Critical depth flumes	6	Excellent*	± 2% with low sediment concentrations *Fair to poor with high sediment loads
B - Fischer-Porter water stage recorders	5	Good	Considerable missing data due to various failures
C - Leopold-Stevens water stage recorders	6	Good	Occasional lost data
3.3 Sedimentation:			
A - Fixed slot (modified Barnes & Frevert)	6	Fair	a - Soils formed aggregates that were larger than slots b - Low flows would occasionally miss slot
B - Rotating sampler (modified Coshocton wheel)	6	Fair	a - Failure of wheel to rotate at low flows b - Plugging of supply tube with sediment from high concentrations
C - Sample collection barrel	6	Good	a - Barrel occasionally overfilled or floated out of hole spilling part of the sample

used in this study. This system was designed for remote sites without power sources, which would only be visited at two week intervals. The system did provide fair to good data on the steeper sites where inundation was not a problem.

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REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM THE NORTHWEST WATERSHED RESEARCH CENTER, BOISE, IDAHO[1/]

C. W. Johnson, C. L. Hanson, G. R. Stephenson, and K. R. Cooley[2/]

INTRODUCTION

The mission of the Northwest Watershed Research Center is to (1) determine precipitation amounts and distributions, including snow accumulation and melt, associated with a wide range of watershed topographic, climatic, soil, and vegetative conditions; (2) study runoff and streamflow characteristics of representative watersheds; and (3) formulate and test models of rangeland productivity, water balance, water quality, streamflow, and erosion as affected by livestock management systems and range improvement practices.

The 90-mi^2 Reynolds Creek Watershed was selected in 1959-60 as an experimental area to represent extensive sagebrush rangelands of the interior Northwest. In the summer of 1960, installation of precipitation and runoff stations began, concurrent with topographic, soil, vegetation, and geologic inventories (Robins et al., 1965). In the following years, meteorological stations, snow courses, soil moisture monitoring sites, and sediment and water quality sampling networks were instrumented.

Since a significant portion of annual precipitation on the experimental watershed is snow, major emphasis was directed to development of techniques and instruments for measuring winter precipitation, snow accumulation, snowmelt, runoff, and sediment transport. Severe winter floods, associated with rain, rapid snowmelt, and frozen soil carry heavy sediment loads and cause serious damage. Numerous problems have been encountered in measuring precipitation and snow under severe wind and temperature conditions; in measuring streamflow with severe ice and heavy sediment loads; and in sampling vegetation, sediment transport, and water quality components.

DATA ACQUISITION PROGRAM

2.1 Precipitation: The precipitation gage network on the Reynolds Creek Watershed was established to measure both rain and snowfall as influenced by elevation and season. Average annual precipitation varies from about 10 inches at the lower elevation (3800 ft) to 43 inches at the 7100 foot elevation. About 56 percent of the annual precipitation falls during November through April at the lower elevations and 76 percent at the high elevation sites, which indicates that a considerable portion of the annual precipitation falls as snow; thus compounding the number of measurement problems.

1/ Contribution from the Northwest Watershed Research Center, Agricultural Research Service, USDA, and Bureau of Land Management, USDI; in cooperation with the Agricultural Experiment Station, University of Idaho, Moscow, Idaho 83843.

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The original gage network, established in 1960-61, consisted of 83 unshielded gages (Hamon, 1971; Hanson et al., 1980). This network was converted to 46 dual-gage sites during 1967-68, because a considerable portion of the annual precipitation was snow and the unshielded gages were not measuring snowfall adequately. The network was further reduced during 1976-77, to 19 sites after a thorough analysis of records to determine which gage sites best represented different areas of the watershed.

The dual-gage installations consist of one shielded and one unshielded weighing-type recording gage (Figure 1). At most sites, the unshielded gage has a 24-hour per revolution time-scale and the shielded gage has a 192-hour per revolution time-scale. The continuous precipitation record for the dual-gage sites is computed using the following equation:

$$\ell n \frac{U}{A} = B \ell n \frac{U}{S} \qquad [1]$$

where, ℓn denotes natural logarithm, A is the computed precipitation, U is the unshielded precipitation, S is the shielded precipitation, and B is a coefficient, (Hamon, 1972; Hamon, 1973; and Hanson et al., 1979). We are using a value of 1.8 for B at the present time (Hamon, 1972); and studies are underway to determine how well this value represents all of the climatic conditions on the Watershed.

The ratio U/S is computed on a storm basis and not at each breakpoint. The continuous breakpoint record is digitized from the 24-hr revolution chart via a digitizing system and stored directly on a computer disk, and then converted to breakpoint values of A by using the U/S ratio obtained from each storm.

The Wyoming shield gage system is being evaluated to determine how well their measured values compare with dual-gage computed values. This system consists of two concentric shields mounted around a weighing-type recording gage, as shown in Figure 2 (Brewer, 1973; Rechard and Larson, 1971; and Rechard, 1975). Preliminary results indicate that rainfall catch by Wyoming shield gages is the same as determined by the dual-gage system, but the results for snowfall are inconclusive.

Most of the gage sites are serviced weekly, because experience has shown that this is the best way to insure a consistent, high quality record. Electric clocks (Belfort Instrument Company) were installed at all sites in 1979. Since then, some sites are serviced every two weeks with very limited loss of data. Gages are also serviced after major storms, along with the regular weekly service schedule. All gages are cleaned and calibrated each fall.

Snow course data are obtained at seven sites twice a month from December 1 until the snow has melted off the courses in the spring. These sites were selected after extensive field investigations of potential sites during both summer and winter conditions. Extensive personnel training was required to insure consistent and reliable snow course sampling because of weather and snowpack conditions. Several alternative snowpack measuring methods, such as snow pillows have been investigated at the Center, and we are operating a snow pillow at one snow course. A thorough review of the installation, operation, and maintenance of snow pillows can be found in Cox et al. (1978).

The precipitation and snow course data gathering and reduction efforts have taken a significant amount of the Center's financial and personnel resources.

2.2 Runoff/Streamflow/Groundwater: The need for accurate streamflow data to support complex hydrologic modeling was recognized from the beginning of the project and watersheds were selected where bedrock exposures made construction of precalibrated weirs or flumes feasible.

Hydraulic laboratory modeling to adapt the Walnut Gulch flumes to the Reynolds Creek Watershed outlet station resulted in development and construction of a modified V-notch weir with a capacity of 20,000 ft^3/sec (Bloomsburg and Tinney, 1961). Major

Figure 1. Typical dual-gage installation.

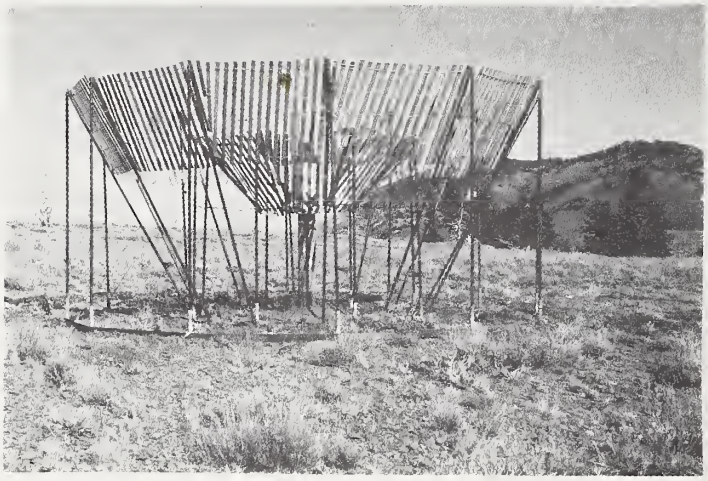

Figure 2. Wyoming shield gage installation.

floods and deposits of coarse sediment upstream from the V-notch weir (Figure 3) caused abnormal flow conditions and inaccurate data, which required expensive sediment removal to produce acceptable measurement accuracy. Concern for quality of streamflow data and plans for weirs at additional sites demanded a permanent solution to the problem. Additional hydraulic laboratory modeling soon produced the drop-box weir (Figure 4), which effectively controlled approach conditions and provided accurate streamflow data (Johnson et al., 1966). Drop-box weirs of various sizes have been constructed and operated successfully at 10 Northwest Watershed Research sites since first designed in 1963.

At streamflow measuring sites and plots where sediment deposition is not a problem, standard 90° V-notch weirs and Belfort FW-1 recorders provide excellent records. Parshall flumes have been used in irrigation ditches and produce excellent records, except where upstream sediment deposition causes abnormal approach conditions.

Weirs and flumes are generally equipped with conventional staff gages, stilling wells, floats, and Leopold-Stevens A-35 recorders. However, because of occasional plugging of inlet pipes with sediment at some stations, auxiliary pressure sensors and recorders insure against loss of records during critical floods. Clocks and recorders are cleaned and repaired regularly.

Recording of streamflow during subzero temperatures has been accomplished by completely enclosing and heating small weirs (capacities less than about 250 ft^3/sec). However, for larger weirs electric or infrared gas heaters are used as necessary.

A major effort has been made in site excavation, bedrock grouting, and preparation of the surface for placing concrete or metal cutoff walls to prevent underflow and seepage around the weirs, and to assure total flow measurements. Laboratory calibration tables and equations are verified by volumetric and current meter flow measurements, except flood discharges, which depend entirely upon laboratory calibrations.

Groundwater level measurements and pump tests are made to determine aquifer storage and recharge characteristics in response to hydrologic conditions on sagebrush rangelands and irrigated areas. Springs and wells are sampled periodically to determine chemical constituents of the groundwater flow systems. Water level changes are measured weekly or bi-weekly by tape or continuously by a combination of Keck water sensors and Stevens Type F recorders. About 90 wells have been drilled and observed for various periods to study groundwater chemistry and hydrology.

2.3 Sediment Concentration/Transport: Hand-operated U.S. DH-48 suspended sediment samplers are used from bridges and weirs, or by wading to obtain depth-integrated sediment concentrations. Sample concentrations are plotted against measured streamflow to determine suspended sediment transport rates and amounts. Results of sediment sampling are also used to determine location of pumping sampler intakes which will represent total stream sediment transport. Because 50-90 percent of annual sediment yield from most study watersheds is produced by a few major runoff events each year, a major goal of the sediment sampling program is to obtain frequent samples at representative sites during flood and snowmelt events (Johnson and Hanson, 1976).

Automatic pumping samplers are used at weirs and flumes to determine suspended sediment concentrations and yields under a wide range of conditions. Generally, Chickasha and ISCO pump samplers function well on small watersheds with concentrations less than 2000 mg/l. However, on watersheds greater than 200 acres, where coarse bedload sediment is common, the U.S. PS-69 samplers are more successful. Details of sediment sampler models, design, and operation are discussed by Allen (1981). Pumping samplers with intakes in drop-box weirs provide excellent results from a minimum number of samples.

Since major runoff and sediment movement on the study watersheds sometimes occurs following periods of subzero temperatures, successful pump sampler operation requires heated enclosures and well designed sampler intakes. Also, solar and wind-powered battery chargers are essential for dependable long-term sampler operation during

Figure 3. The modified V-notch weir at the outlet of the 90-mi^2 Reynolds Creek Watershed following a flood of 3800 ft^3/sec, December, 1964. Design capacity 20,000 ft^3/sec and top opening 97 ft.

Figure 4. A drop-box weir on the 14 mi^2 Salmon Creek Watershed, a subwatershed of Reynolds Creek. Design capacity 7,000 ft^3/sec and top opening 52 ft.

snowmelt runoff. Overall, considerable equipment and personnel are required to obtain adequate sediment samples with extremes of temperature, a wide range of site conditions, and numerous unexpected instrument problems at remote sites.

Sampling and particle-size analysis of bedload sediments were reported by Johnson and Smith (1978). Bedload samplers of the type designed by Helley and Smith (1971) and tested by Johnson et al. (1977) are used to determine bedload transport-streamflow relationships. Complete calibration and testing of this type of bedload sampler is still in progress at the St. Anthony Falls Interagency Sedimentation Laboratory, Minneapolis, Minnesota.

2.4 Water Quality: Chemical Concentrations - Concentration of the chemical constituents associated with streamflow have been determined for both the dissolved and adsorbed states. Samples have been obtained by U.S. DH-48 hand samplers and from automatic pumping samplers, which are used for suspended sediment determination at weirs and flumes. Samples are usually taken at regular schedules during low flow (baseflow conditions) at weirs, flumes, and other stream segments where flows are measured. More frequent samples have also been taken at weirs and flumes during peak flow from rainstorm and snowmelt events.

Samples are immediately taken to the lab and analyzed for standard ionic and nonionic concentrations. Laboratory equipment for determining concentrations include standard spectrophotometer for measuring light transmittance, atomic adsorption spectrophotometer, ionalyzers, and other standard wet chemistry equipment. Every effort is made to either analyze samples immediately, or fix, and/or freeze them because of the potential for rapid deterioration of some chemical elements.

Bacterial Concentrations - Samples for bacterial analyses of rangeland streams are taken in sterile bottles by hand, within the top 10 cm of the water surface. Because of chances of contamination, automatic samplers are not used for bacteria tests. Depth integrating samples are seldom used because of similar contamination possibilities. Sample contamination is a constant threat and must be recognized and prevented.

Lateral sampling tests within the top 10 cm have been done at most sites to determine sample variability. All samples are incubated within 12 hours.

The Membrane Filter (MF) method is used for all bacteria (total coliform, fecal coliform, and fecal strep.) analyses of waters with low suspended solids. When the suspended solid concentrations are such that individual colony enumeration is difficult by the MF method, the multiple-tube fermentation procedure is followed with results reported as a Most Probable Number (MPN) index. The index number is not a direct colony count and less precise than the MF method. The methods used, therefore, will vary with the particular study, depending primarily on whether suspended solids are involved (Stephenson and Street, 1978; Rychert and Stephenson, 1981; and Stephenson and Rychert, 1982).

DATA QUALITY PROBLEMS

3.1 Precipitation: The major problems with measuring rain and snowfall are the amount of time and the personnel required to obtain accurate data. The service time for most remote sites has been cut by reducing the number of sites and installing the new Belfort electric clocks, which have operated very well. Problems in obtaining consistent snow water content data have been alleviated through personnel training. Other problems encountered and what has been done to correct, or at least reduce these problems, are listed in Table 1.

3.2 Runoff/Streamflow/Groundwater: Original streamflow gaging stations with natural controls were unacceptable on Reynolds Creek because of extreme changes in channel cross-sections during flood events. Therefore, precalibrated weirs or flumes were installed at all stations (Table 1). Generally, few problems have been experienced in

Table 1. Data Quality Evaluation

Description of current stations	Estimate of data quality	Special problems and comments: problem	Special problems and comments: solution
3.1 Precipitation:			
A - Standard weighing and recording gages (Belfort Instrument Company)	Good	Clock stopping	Electric clocks and frequent service
		Snow capping	Painted collector black
		Pen caught under drum in hail storms or snow capping	Placed a small wire under the pen arm
		Dash pots freezing	Used antifreeze in dash pots
B - Snow courses	Good	Obtaining consistent data	Observer training
		Site selection	Thorough site evaluation
3.2 Runoff/Streamflow/Groundwater:			
A - Drop-box weirs	Excellent	Ice	Installed heaters and enclosures
B - 90° V-notch weirs	Excellent	Ice	Installed heated enclosures
C - SCOV weir	Fair - poor	Upstream sediment deposits	Mechanical cleaning
D - Groundwater - recorders	Good - fair	Battery failures, freezing, blowing snow	Improved enclosures
E - Groundwater - tape measurement	Excellent	Tape error	Technician training
3.3 Sedimentation:			
A - P.S. 69 automatic pumping samplers	Good	Representative sampling	Drop-box intake
B - Chickasha automatic pumping sampler	Excellent	Pump failure - coarse sediment	Use for low concentration only
C - ISCO portable pumping samplers	Good - fair	Battery failures and freezing difficulties	Large batteries, enclosures
D - Helley-Smith bedload samplers	Unknown	Calibration unknown	Laboratory calibration in progress
3.4 Water Quality:			
A - Chemical concentrations	Good - excellent	Sample variability	Used standard procedures
B - Bacteriological concentrations	Good	Contamination delayed	Used sterile containers, rapid handling, and refrigeration

obtaining excellent quality streamflow records at weirs during low flow, except during subzero weather. In a few cases, ice buildup at large weirs was too severe for removal by heaters or mechanical means and streamflow was estimated. However, severe icing is usually during baseflow periods and inaccuracy does not adversely influence snowmelt and flood analysis. Heating stilling wells and inlet pipes is of utmost importance to assure rapid response to snowmelt and storm runoff following extreme cold.

During and following flood events, the greatest problem is sediment deposition and scour in the weir approach, such as in Figure 3. The drop-box weirs have solved this difficult problem and pass even large boulders. Also, the drop-box weirs facilitate design of flushing systems to keep stilling wells and intakes free of sediment.

Streamflow recorder malfunctions, failures of clocks and inking systems, and vandalism are continuous problems and justify weekly or more frequent servicing at most stations to assure quality data (Table 1). Also, backup recorders and pressure transducers or other auxiliary systems prevent loss of important data.

Groundwater measurements and sampling in small diameter wells is often difficult, especially during periods of rapid recharge. Frequent field checks and instrument maintenance are critical in obtaining quality data. Winter operation of recorders is complicated by blowing snow and battery failures when data are critical.

3.3 Sediment Concentration/Transport: Automatic pumping samplers at remote sites with difficult access during storms and floods present numerous problems in obtaining samples representative of widely varying flow conditions. Most frequently experienced failures are electronic switches and controls, mechanical malfunctions of pumps, plumbing leaks, advancing mechanisms, and battery power systems (Table 1). Availability of an experienced electronic technician is most important in keeping samplers operating properly.

Representativeness of individual samples is ever a problem, which demands all the duplicate sampling feasible. Thus, concurrent hand-operated sampling and pump sampling is necessary during major events. Often this requires working during heavy rain, cold, and darkness. The need for well trained technicians cannot be overemphasized.

3.4 Water Quality: Chemical Concentrations - Interpretation of chemical concentrations of streamflow on watershed basins is difficult because of great variability in several factors: 1) natural background conditions caused by soil and geologic differences; 2) management practices; and 3) seasonal and weather changes. To accurately determine the chemical concentrations (in both the dissolved and adsorbed states), and to understand inter-relationships, these variables must be a part of the research. Quality results depend on accurate precipitation and streamflow measurement and accounting for management changes, irrigation return flows, grazing practices, herbicide and pesticide application, and soil and geologic variabilities. Often the number of samples analyzed is not commensurate with our needs because of the high cost of analytical determinations or the lack of help necessary to complete the assays. Strict adherance to standard methods and procedures minimizes sample variability.

Bacterial Analyses - Because of low background concentration of most chemical constituents and the absence of applied herbicides, pesticides, and fertilizers at our research sites, we have concentrated on bacterial indicators to denote changes in management practices, irrigation return flows, and streamflow variations. Generally, the cost per sample of bacterial analyses is considerably less than chemical analyses.

Greatest problems are contamination and communication. Sample contamination with foreign microbes (microorganisms foreign to the sample site) is difficult to prevent, and usually necessitates visiting sites during storm flows and changes

in management (moving cattle from one study basin to another, or irrigation runoff changes). The use of automatic samplers is not recommended unless sterile conditions can be assured.

Communication problems arise because we do not have full control or knowledge of management changes. It is often difficult to obtain accurate cattle numbers and dates when cattle are moved from one grazing allotment to another.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

1. Establish a training program for scientists and technicians in use of recently developed instruments and devices currently available for watershed research.

2. Assign a committee or contract with recognized experts to independently evaluate quality of watershed data at different locations and make recommendations for improvement. This would include establishing criteria and sampling procedures to obtain data sets for evaluation and writing standards.

3. Set aside funds and assign scientists to perform laboratory tests on weirs and flumes needing additional calibration and testing, such as full capacity of drop-box weirs.

4. Investigate available battery and recharge systems to meet power and heating needs at remote sites.

5. Investigate improved shields and procedures for measuring precipitation with snow and wind.

6. Compare results from new sediment particle size analyzers with commonly used methods of sediment analysis.

7. Investigate sediment sampling intake systems and representativeness of present sampling methods.

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QUALITY OF WATERSHED RELATED DATA COLLECTED AT THE SNAKE RIVER CONSERVATION RESEARCH CENTER

D. L. Carter, Supervisory Soil Scientist

1.0 INTRODUCTION

The mission of the Center is broad and encompasses research on a wide variety of soil, water and energy problems prevalent on irrigated and dryland farms. Research objectives are directed toward regional problems. Research is conducted under three research units: (1) Water Management, (2) Soil Management and Water Quality, and (3) Entomology. Much of the research is directed toward developing practices to improve production efficiency on farms by conserving energy, soil, water and plant nutrients.

2.0 DATA ACQUISITION PROGRAM

2.1 Precipitation: Precipitation is measured at the Center by the National Oceanic and Atmospheric Administration as part of a National Weather Station measurements. It is also measured by two recording lysimeters located about 0.5 miles from the National Weather Station. Nonrecording rain gauges are utilized off-station, particularly on nonirrigated research sites.

2.2 Runoff: Runoff is measured by precalibrated flumes, weirs and on occasion by current metering. Most of the stream flow measurements are on irrigation furrows, but some measurements are made on field and farm runoff streams. A few sites on main irrigation return flow streams are measured by recording hydrographs.

2.3 Sediment Concentrations: Sediment concentrations are measured by filtering known volume samples, drying the filters, and weighing the sediment. Correlation and regression relationships have been developed between Imhoff cone readings and weighed sediment for about 350 samples. Cone readings taken at 20, 25, and 30 minutes gave correlation coefficients of 0.93, 0.95, and 0.96, respectively on silt loam soils. One hour cone readings do not give satisfactory relationships.

2.4 Chemical Concentrations: The concentrations of dissolved and adsorbed chemicals in runoff waters as well as irrigation inflow waters are measured by standard methods. The Center is equipped with appropriate spectrophotometers, atomic absorption spectrometers, conductivity bridges, etc., to make all measurements; except that pesticide measurements are not made at the Center.

3.0 DATA QUALITY PROBLEMS

3.1 Precipitation: The Center is located in a low precipitation area of about 8.5 inches per year. The accuracy of data provided by the National Weather Service is adequate. Similarly, precipitation measured by nonrecording rain gauges at nonirrigated sites is sufficiently accurate for purposes at the Center.

3.2 Runoff: Runoff measurements are generally replicated several times to obtain mean values for irrigation furrows. Occasionally, plugged inlets or equipment failure is encountered at recording stations. Personnel maintaining stations are aware of these problems and how to recognize and solve them so that minimal impact on data accuracy results.

3.3 Sediment Concentrations: Sediment concentration measurements are labor intensive, and we make a thousand or more each irrigation season. Generally the entire furrow

stream is collected for a short period as a sample, and our interest is primarily in total sediment. Therefore, we have few sampling problems. On larger streams we sample at drop structures with a slotted sampler to provide a representative sample.

3.4 Chemical Concentrations: Chemical concentration measurements are also labor intensive. A major portion of our technician time is utilized in this effort. Samples are refrigerated until analyses are made to minimize changes induced by elevated temperatures. We encounter few problems in analyses, because standard methods are carefully followed. The Center is well equipped for chemical analyses and staffed with well trained scientists with strong chemical backgrounds. Thus, procedural problems are generally solved quickly.

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CHAPTER 'A' WATER DATA LABORATORY

By J. B. Burford[1]

1. INTRODUCTION

The Agricultural Research Service (ARS) research activities related to watershed hydrology are not data collection programs per se, but data are essential and prerequisite to most research accomplishments. Therefore, data collecting, processing and handling are important phases of the overall research programs and must be acknowledged as such. Besides meeting the immediate needs of the particular research study, these data often have uses that trancend those for which they were originally gathered.

When computer faciltites became available to hydrologic data users during the mid 1960's, the value of large volumes of data increased and the capabilities for handling them were created. By this time much of the ARS hydrologic research data was being obtained in, or converted to digitized form and computer processed by the several locations, using an assortment of techniques and procedures. The ARS recognized the value of these unique data volumes and initiated efforts to develop a standarized system for their storage and retrieval at a central location. These efforts resulted in creating the Hydrology Data Laboratory, now the Water Data Laboratory (WDL), early in 1969. The mission of the WDL is to : (a) develop and maintain a computerized data bank for the water related data obtained by the various ARS research projects, and (b) to summarize hydrologic data obtained by the ARS watershed research projects for publication in annual volumes. The WDL is located at Beltsville Agricultural Research Center, within the Plant Physiology Institute, at Beltsville, Maryland. The facilities of the USDA Wathington D. C. Computer Center are used for processing and storing of water related data as required for data bank development and maintenance.

2. DATA ACQUISITION

Water related data, primarily precipitation and streamflow, from experimental watersheds are obtained by the several ARS watershed research projects. The data are processed at the locations and sent to the WDL for reviewing, format standardizing, data bank storing, cataloging and indexing. Efforts are underway to obtain and store other water related data in the data bank, but only small amounts have been received.

The WDL has continuing activities related to converting to digital form, data recorded in tabular or analog form obtained at locations, now terminated, or at continuing locations prior to the computer era.

2.1 Precipitation Data and 2.2 Streamflow Data

Most of the precipitation and streamflow data are received by the WDL in breakpoint form, after having been processed by the sending locations. The data are processed by the WDL into uniform formats, retaining the breakpoint detail, including time interval intensities and amounts, for the precipitation data, and time interval runoff rates and amounts, for streamflow data.

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3. DATA QUALITY EVALUATION

3.1 Precipitation Data and 3.2 Streamflow Data

Daily and monthly precipitation and streamflow values, produced from the data bank data, are compared to corresponding values compiled by the sending locations. Resulting differences are reconciled. Occasionally this procedure provides opportunities for improvement in the integrity.

The quality of precipitation and streamflow data stored in the data bank is equal to or better that the quality of the corresponding data as received from the originating locations.

LABORATORY TESTS OF WATER LEVEL RECORDERS AND BROAD-CRESTED V-NOTCH WEIRS FROM THE ST. ANTHONY FALLS HYDRAULIC LABORATORY
Minneapolis, Minnesota

by

Fred W. Blaisdell

1.0 INTRODUCTION

The mission of the Hydraulics of Structures Research Unit at the St. Anthony Falls Hydraulic Laboratory (SAF) is to develop improved and new structures for the control, use, management, and measurement of water. Primary emphasis since the establishment of the project in 1940 has been on the development of generalized design criteria for hydraulic structures used by the Soil Conservation Service. A limited number of model studies of specific structures have been made. Similarly, a limited number of studies on flow measuring devices have been made for the Agricultural Research Service (ARS): In the early 1940's studies were made by Huff (8, 9, 10) of broad-crested V-notch weirs with heavy upstream silt deposits and steep fixed slopes approaching the weirs, and in the late 1950's Johnson (11) made model studies of two weirs for the Sleepers River Watershed in Vermont.

To the writer's knowledge, no nationally-sponsored effort has been expended since about 1942 by ARS and its predecessors on research instrumentation used by the ARS in its watershed investigations. However, nationally-sponsored instrumentation research to support field flow measurement and sampling was done in the 1930's by units stationed at the National Bureau of Standards and Cornell University. These research efforts developed the broad-crested V-notch weir (7), the H flume (6), and the multislot divisor (2), and determined the accuracy and precision of several types of water level recorders (1). More recent locally-sponsored research has resulted in: 1) The Walnut Gulch flume developed at the Stillwater, Oklahoma, Water Conservation Structures Laboratory (WCSL) for the Southwest Rangeland Watershed Research Center (SWRWRC) (5); 2) the drop box weir developed at Washington State University for the Northwest Watershed Research Center (4); 3) information on silt deposition effects on the ratings of broad-crested V-notch weirs by Colorado State University (CSU) for the Columbia, Missouri, Watershed Research Unit (12, 15); and 4) development of the Coshocton runoff sampler at SAF and WCSL (13, 14, 3). The high velocity Santa Rita flume (16) developed at SWRWRC has been used at other locations but has received only cursory physical checks, some of which indicate that some measurements of discharge may be of poor quality.

2.0 DATA ACQUISITION SYSTEM

2.1 Precipitation: No precipitation data collected at SAF.

2.2 Runoff/Streamflow: The only element of the data acquisition system reported here is tests of float type water level recorders conducted at the Hydraulic Laboratory of the National Bureau of Standards, Washington, D.C., in the late 1930's by Blaisdell (1).

2.2.1 Water Level Recorders: 113 tests on 38 water level recorders of 11 different types made by 4 different manufacturers were made by mounting each recorder over a water tank and comparing the chart record with the level determined with a point gage. Because chart paper dimensions are affected by humidity changes, these effects were also studied. An analytical study evaluated the factors influencing recording accuracy.

2.2.1.1. Factors Affecting Recording Accuracy: There are 9 sources of error in the

stage recording mechanism of float type water level recorders. Each of these is discussed in turn. The FW-1 recorder tests are used as examples of the error magnitudes. Space limitations prevent discussing the performance of the other recorders tested.

2.2.1.1.1. Friction: The force required to operate a water level recorder manifests itself in the float submergence required to develop the operating force. Deeper float submergence provides the operating force on rising stages and shallower float submergence occurs on falling stages. The difference is float lag. The required operating force depends on the recorder friction plus additional friction if maintenance is not adequate. Modification of the recorder by the addition in the field of float operated components can cause additional lag. Float lag causes a period of no change in recorded stage during stage reversal. Laboratory tests show that the float lag for the FW-1 recorder with a 6-inch float averages 0.0012 ft.

The correction for float lag can be eliminated on rising (falling) stages by setting the recorder on a rising (falling) stage. The true height on a falling (rising) stage can be obtained by subtracting (adding) the float lag correction to the falling (rising) stage.

2.2.1.1.2. Line Shift: As the stage changes, the line between the float and the counterpoise shifts from one side of the float wheel to the other side. This progressively decreases float submergence on rising stages and increases float submergence on falling stages.

For small stage changes the correction for line shift possibly can be neglected; for a 6-inch diameter float and a line weight of 0.0092 lb/ft the correction is 0.0015 ft/ft of stage change.

2.2.1.1.3. Counterpoise and Line Submergence: If the recorder is set so the counterpoise submerges on rising stages, the float submergence will increase. The stage error varies significantly during counterpoise submergence and at a lesser rate due to line submergence after complete counterpoise submergence.

Counterpoise and line submergence corrections can be avoided by setting the recorder high enough to prevent submergence. Alternatively, an auxiliary float wheel can be used to locate the counterpoise where it will not be submerged. However, some auxiliary pulleys tested had friction greatly exceeding that of the recorder that caused an additional float lag of several hundredths of a foot. Counterpoise submergence for an FW-1 counterpoise and a 6-inch diameter float caused an error of 0.009 ft. Line submergence caused an error of 0.0015 ft/ft.

2.2.1.1.4. Surface Tension: The meniscus resulting from surface tension can cause the float to set either higher or lower in the water depending on whether the meniscus is convex or concave. A reversal of meniscus curvature is possible as the stage changes from rising to falling and vice versa.

The maximum correction for surface tension effect is:

Float diameter - inches	3	6	12
Correction - feet	0.0026	0.0012	0.0006

2.2.1.1.5. Momentum: It is possible for the change in the rate of change of stage to be so great that the momentum of the moving parts of the recorder will result in an error in recording the true stage.

If the moving parts weigh 3.54 lb, the float is 6 in. in diameter, and the change in the rate of change of stage is 0.2 ft/sec^2, the correction would amount to 0.002 ft.

2.2.1.1.6. Backlash: Design or workmanship of the recorder may be such that there is play in the mechanism. The play can sometimes be eliminated by adjustment. The amount of play can be detected by fixing the float wheel and rotating the moving parts by hand.

Backlash has the same effect on the stage record as float lag and can be combined

with the float lag correction.

2.2.1.1.7. Instrument Errors: Some errors are inherent in the manufacturing process. In 1936 the FW-1 cam was formed using an 8-times size master cam and a pantograph engraving machine. Consistent errors in the cam shape were a principal source of error. This error can be corrected if the recorders are calibrated. Average errors of ±0.008 ft were measured.

Because of the method of manufacture, the least accurate points on the cam are at the cusps. For this reason, setting the zero stage at the edge of the chart should be avoided.

An adjustment screw for the pin arm length is provided on the FW-1 recorder. The correct center-to-center length is 1.031 inches. Adjustment of this length to cause the pen to travel the full width of a chart that is wider than 5.00 inches causes the cam pin to rest on the cam at an incorrect angle. The correct length should not be changed.

Changing the pen arm length changes its radius and the changed radius is different than the radius of the chart lines. The correct length is 6-31/32 inches.

On occasion the tape would ride on a float wheel peg. The error amounted to about 0.004 ft. Pegs were also found to increase float lag by 0.0008 ft. A float wheel without pegs overcomes this problem and, if the float wheel is sized correctly, the line shift error is automatically corrected. Absence of pegs did not result in line slippage in the laboratory.

2.2.1.1.8. Line Length Changes: Temperature changes between the time the recorder is set to read correctly and the time of recording will cause errors. Temperature corrections depend on the float line length and material, the height and material of the recorder support, the stage, etc.

If the float cable has a hemp core, humidity changes will change the line length. This source or error can be avoided by not using a cable affected by humidity.

2.2.1.1.9. Chart Expansion: The chart paper will change its dimensions with relative humidity changes. A relative humidity change from 30 to 90 percent will change the chart dimension in the cross-machine direction by 0.8 to 1.5 percent and in the machine direction by 0.3 to 0.5 percent. Corrections for incorrect chart widths should be made if high accuracy is required. Such corrections will require a means of determining the chart width at the time the record is made and again at the time the chart is read.

2.2.1.1.10. Overall Accuracy: Under laboratory conditions, the writer has been able to obtain water level recorder readings that agree with point gage readings to within 0.001 to 0.002 ft if all the various corrections are applied. However, tests of 22 FW-1 recorders showed maximum and minimum differences from the point gage value of +0.008 and -0.007 ft--a spread of 0.015 ft--after correcting only for line shift and chart expansion.

3.0 DATA QUALITY

Some work that has been done on ARS watershed instrumentation at SAF and at other locations will be discussed. These studies have identified problems related to the accuracy and precision of flow measurement.

3.1 Precipitation: There are no watersheds or plots at SAF, so no precipitation data have been obtained.

3.2. Runoff/Streamflow: Sediment in the flow can affect both the accuracy and precision of flow measurement. For example, following discussions will show that the broad-crested V-notch weir has low and undeterminable accuracy if heavy sediment loads deposit in the approach channel. If a high velocity Walnut Gulch or Santa Rita measuring flume is used so sediment is transported through the flume, the flume rating may produce less precise data, but the lack of sediment deposition will improve the measurement accuracy. Many of the problems regarding data quality

encountered at ARS watershed measurement installations are related to the presence of sediment in the flow.

3.2.1. Broad-crested V-notch Weirs: The results of tests at the National Bureau of Standards (NBS), at Cornell University, at SAF, and at CSU will be summarized to illustrate the problems that exist when these weirs are used in streams carrying heavy loads of sediment.

3.2.1.1. National Bureau of Standards Tests: The first tests on the broad-crested V-notch weir were done in 1937 by A. N. Huff at the Hydraulic Laboratory of the NBS in Washington, D.C. One-fifth-size models of different crest shapes, horizontal and V-notch transverse slopes, and a range of approach channel depths, configurations and slopes were tested in a 10-in. wide flume. The results were not reported.

3.2.1.2. Cornell University Tests: Tests on broad-crested weirs were continued by A. N. Huff at Cornell University, Ithaca, N.Y., in 1938. Six unpublished reports present the findings (7). They are titled: Report No. 1, "Test of 16-inch Weir and Comparison with 30-inch Weir;" Report No. 2, "Effect of Upstream Silting on Measuring Weir;" Report No. 3, "Drawdown of Water Surface in Upstream Channel and Drawdown in Intake Pipes;" Report No. 4, "Effect of Dykes on Rating of Measuring Weir;" Report No. 5, "Tests of Vega Desilting Flume with 1/5 scale 2:1 V-Notch;" and Report No. 6, "Coefficients for 2:1 and 3:1 V-Notch Weirs and Method of Computing Ratings."

Report No. 1 is on tests of horizontal and triangular weir crests with both free and submerged flow. In Report No. 2 no serious effect of silt on the ratings is mentioned. In Report No. 3 it is stated that there is a 3.5 percent difference in discharge computed using the lower head observed when the intake is at the center of the channel compared to the head measured at the side of the channel. The dikes used for the tests of Report No. 4 were to prevent flows from bypassing the weir. The dikes were 5 ft apart at the weir and the approach channel was level with the weir notch. The flume in Report No. 5 began 0.09 ft below the crest of the V-notch, extended 10 ft to the intake on a 1 percent slope, and continued upstream on a 2 percent slope for another 15 ft. There was very little effect of the desilting flume on the weir rating. This is contrary to later findings at SAF. The subject of this report indicates that sediment deposition problems were recognized soon after the broad-crested V-notch weir was installed in the field. In Report No. 6 head-discharge coefficient curves are developed from experimental data.

3.2.1.3. St. Anthony Falls Hydraulic Laboratory Tests: The SAF tests were on models of installations where desilting flumes had been installed upstream of the weir crest and models of the weirs proposed for the Sleepers River Watershed in Vermont.

3.2.1.3.1 Desilting Flume Tests: Wood or concrete V-shaped flumes were installed for 25 ft upstream of many broad-crested weirs that had silted to the crest level. These flumes began just below crest level and sloped upward in an upstream direction. Slopes of 2.5 percent were common. Field photographs show silt deposits in many of these desilting flumes. The flumes modeled at SAF in 1941 had been installed at locations in Santa Paula and Watsonville, California (8); Americus, Georgia (8, 10); Blacksburg, Virginia (8); Vega (10) and Waco, Texas; Dayton, Washington (10); Safford, Arizona; and Hastings, Nebraska. Rating tables based on the model tests were prepared. Most of the rating curves were irregular, some logarithmic plots showing curved lines and others wavy lines. One rating curve shows a range of discharges at a constant head and another curve shows three discharges at the same head. These irregularities were a result of supercritical flows in the desilting flumes and standing waves that moved across the stilling well intake as the discharge changed. These experiences of the early 1940's showed that the broad-crested V-notch weir is not a suitable device for measuring flows heavily laden with sediment.

3.2.1.3.2. Sleepers River 16.6 square mile drainage area site: At this site the approach channel slope is about 1.5 percent and the bed is virtually paved with

1 cubic foot rock. A 10:1 weir had to be used to limit the head increase to prevent flooding a road. As a result, flow approaching the weir became supercritical as the discharge increased. Also, the head-discharge relationship was extremely sensitive to channel roughness and for two roughnesses tested the flow could vary over a range of 1,000 cfs with no change in head. Discharge errors exceeding 100 percent are possible.

These model tests pointed out problems to be expected and showed that field measurements would be required to define the rating at flows exceeding about 800 cfs. This is only 11 percent of the 7,000 cfs design flow.

3.2.1.3.3. Houghton Brook 16.8 square mile drainage area site: Three locations for the weir were tested. Ledge rock, channel curvature, and a steep channel slope (4 percent) created problems. At one location the approach velocity was so high that 0.5- to 4-foot rock in the approach channel was scoured at the maximum discharge. Asymmetrical flow approaching the weir at two locations required a baffle wall to redirect the flow. At the second location tested, a seiche caused fluctuations in the gage record. At a third and recommended location, 8-inch rock fill level with the weir crest for 30 feet upstream was recommended to reduce the effect of deposition upstream of the weir on the weir rating. If the fill scours, the effect on the discharge is a reduction of 15 percent. Fine material deposited on the level approach during high flows caused a deviation of up to 7 percent from the calibration at lower flows.

These results of the Sleepers River Watershed model tests give an indication of some problems and their magnitude that can affect runoff measurements.

3.2.1.4. Colorado State University Tests: Broad-crested V-notch weirs were tested at CSU with approach channels narrower than those used in the Cornell tests, with sloping approach channels, and with sediment deposits in the approach channel. The V-notches had slopes of 2 and 3 horizontal to 1 vertical. The approach channel slopes tested were 0.0, 0.5, 1.0 and 1.5 percent. Sediment deposits at the head measuring intake were 0.5 and 1.0 feet deep and sloped to a zero depth at the weir. The following comments are taken from the summary chapter of the report by Ruff, Saxton and Dang (15).

> The results are difficult to apply because of the uncertainty in the field of identifying where deposits are present and what are the heights of the deposits. . . . The effect of the sediment deposition was . . . not consistant throughout the flow range tested.
>
> Flow near critical or supercritical flow was observed at the intake . . . at the greater slopes and was accompanied by waves on the water surface. At slopes of 1.0 percent and 1.5 percent, standing waves formed over the intake. . . . when the flow becomes critical or supercritical at the intake . . . waves . . . cause wide fluctuations in the stilling well water level. The water depth is dependent upon the channel characteristics and the weir is no longer the controlling section.
>
> The selection of a curve to represent a specific gaging site depends not only upon the approach channel cross-section and slope, but the channel roughness. The assessment and translation of the field channel roughness to that of the laboratory curves is difficult, . . . the smaller channel cross sections caused increased flow rates for a given head due to increased approach velocities. . . . the rating curves developed in this study and those based on the rating table in Agricultural Handbook No. 224 . . . may be in error by as much as 100 percent . . ..

4.0 RECOMMENDATIONS

Make a complete study of instrumentation required for the measurement and sampling of flows heavily laden with sediment. Some of the sub-items are listed below.

4.1 Supercritical Flow Flume: The Santa Rita supercritical flume developed at SWRWRC needs physical tests to determine its characteristics, potentials, limitations, and rating. Preliminary verbal comments indicate that friction factor changes with the flow depth need to be considered in the mathematical rating, that the flow capacity may be less than indicated by the mathematical rating, and that standing waves that move over the intake with changing flow rates may exist. A product of the study should be standardized flume design and rating criteria. Many flumes are in current use at each of at least 4 ARS locations and calibration data are needed before field data can be analyzed and the data accuracy and precision established.

4.2. Drop Box Weir: The drop box weir developed at Washington State University has never been calibrated for the higher flows. The calibration needs to be completed using heavy sediment loads before field data now being obtained at some ARS locations can be analyzed.

4.3. Flow Sampling: No satisfactory fully tested device exists for obtaining representative samples of the flow for sediment and water quality analyses. Such a device is cited as a critical need at several ARS field locations.

4.4 Flow Depth Measurement: Many problems exist in the measurement of depths in sediment laden flow with stilling wells. A device to measure flow depths where the sediment load is high should be independently but simultaneously developed with the flume and weir listed above.

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REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM THE NORTH CENTRAL SOIL CONSERVATION RESEARCH LABORATORY

by

C. A. Onstad

1. INTRODUCTION

The laboratory mission is to conduct research on soil and water conservation problems in the northern Corn Belt to insure maximum productivity with minimum detrimental effects on the environment. In this context four research goals have been established:

(1) Determine the effects of conservation tillage practices on soil chemical, physical, and biological properties and their relation to production potential.

(2) Increase the efficiency of water use by crops where precipitation and temperatures are below optimum.

(3) Evaluate the influence of and develop agricultural practices for the safe and efficient application of agricultural wastes to the land.

(4) Conduct basic and applied research for the control of soil erosion by water in the northern Corn Belt.

Data collected from the various experiments are used to study plant reactions to various soil management practices. Data are also used to develop and verify soil management models designed to optimize crop production in an area characterized by (1) poorly distributed rainfall for crop growth; (2) runoff losses from intense summer storms and snowmelt; (3) high erosion potential when the soil surface is most vulnerable; and (4) nutrient accumulation in surface and subsurface waters.

2. DATA ACQUISITION PROGRAM

2.1 Precipitation: Generally, precipitation measurements are needed for relatively small areas for most of our field experiments because they are usually conducted on small plots covering areas of only a few hectares, at most. Consequently, the few raingages that are in use are intensively maintained and do not need to be synchronized, time-wise. Raingages being used are of the standard weighing type using 6-hour clocks for accurate intensity determinations. These have served satisfactorily with few problems.

Although we have a need to measure snowfall, we very seldom do for two reasons. First, raingages do a poor job because of wind and mechanical problems brought on by cold weather. Secondly, snow accumulations rarely remain in place during our winter because of drifting conditions. At the end of the winter season, nearly all snow has been trapped in shelterbelts and standing crop residues. Making accurate measurements under these conditions is very difficult and new methods need to be explored.

2.2 Runoff/Streamflow: Because most of our experiments where runoff measurements are needed are conducted on small plots, standard H-type flumes or runoff containment types of measuring equipment are used. Accurate measurements of runoff rates are made using the H-flumes although high sediment loads occasionally have altered inlet

conditions and stilling well levels. Volumetric tanks equipped with a stage recorder and a multislot divisor or a small V-notch weir part way up the tank are also being used. Runoff rates are measured using a combination of volume changes and stage above the V-notch or divisor. Accurate runoff measurements are made using these methods.

On some very small plots used for some infiltration experiments, plot runoff was transferred to a cylindrical tank equipped with a stage height recorder using a vacuum system. The suction side of a common shop vacuum cleaner containing a tube is attached to the runoff collection trough at the downslope end of the plot. Runoff is transferred to the measuring tank where stage is measured. We have found this to be a very good method for measuring runoff on small plots.

2.3 Sediment Concentration: Measuring sediment concentrations with time is a very laborious task if good accuracy is to be obtained. This is because the most common way is to "grab" sample at predetermined time intervals during experiments where artificial rainfall is applied. For natural sediment producing events, pumping samplers are used. Generally, pumping samplers collect samples from a single point in flowing water rather than sampling the entire cross-section of flow. In order to adequately define rapidly changing concentrations such as that near the beginning of a runoff event, many samples need to be taken. After the samples have been collected they need to be weighed, etc. which is accurate but tedious.

A new instrument that continuously measures fluid density shows promise for measuring sediment concentration. If the electronics of the system can be made more stable, or if the instrument can be used in a configuration such that zero drift is minimized, this instrument will be used extensively for collecting data to investigate and simulate the dynamics of erosion and sediment losses from fields.

2.4 Water Quality: Concentrations of dissolved and adsorbed chemicals in runoff are routinely and accurately measured using an atomic absorption spectrophotometer, and autoanalyzer, and Kjeldahl apparatus. However, the problems associated with collecting sediment samples also apply to water quality sample collection.

3. DATA QUALITY PROBLEMS

3.1 Precipitation: The major problem with precipitation measurements is that of measuring snowfall and mixtures of rain and snow. During high wind conditions experienced in West Central Minnesota, snow catch measurements in raingages are relatively unreliable. Equally difficult to measure are the amounts of snow on the ground due to drifting conditions. On large watersheds, the problem is minimized because the snow is relocated in shelterbelts, ditches, etc. However, on small watersheds the snow may be completely lost and transferred to another watershed.

3.2 Runoff: The biggest problem associated with measuring runoff from natural plots and small watersheds is intermittent freeze-thaw cycles that occur nearly every day for 2-3 weeks during early spring. Under these conditions, floats freeze in stilling wells, intakes freeze, and sometimes an ice crust forms in the approach. Unless these conditions are corrected daily, erroneous measurements are recorded.

3.3 Sediment Concentration: The selection of an appropriate sampling point is an important consideration for collecting sediment concentration data. There is not sufficient information in the literature to provide guidelines in this area so that biases with regard to sampling point are unknown.

Also important for studying erosion dynamics are the particle-size distributions of sediments. Primary particles are important but researchers are finding that most sediments are comprised of aggregates of varying size distributions. Accurate

determinations of aggregate size distribution are indeed difficult due to problems of stability and varying densities. Very little is known about correct procedure and techniques for these types of measurements in the field.

On runoff plots where data are collected from artificial rainfall, the entire flow is usually collected for a short time period. On some natural runoff plots, all the runoff from storms smaller than some design level is collected. This gives good accuracy for total amounts of sediment but does not provide a concentration distribution with time which is now increasingly needed for investigating erosion dynamics.

3.4 Water Quality: Problems with sample collection for water quality determinations are the same as for collecting samples for determination of sediment concentrations. However, sample handling methods after collection are also very important for good quality chemical determinations. For example, some chemical components change quickly with time or elevated temperatures. For the former, equipment and samples must be serviced quickly to obtain meaningful results, and for the later, samples must be refrigerated immediately after collection to provide correct analysis. Both cases are labor-intensive for accurate results.

4. RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH.

1. Develop and test instrumentation to continuously measure sediment concentration with time for both natural and artificial storm events.

2. Develop a procedure to measure aggregate densities and "fix" sediment material for particle size determinations.

3. Develop means of measuring snow on tilled fields with varying residue management practices.

4. Develop guidelines for positioning sampler intakes for both sediment and chemical determination.

NORTH CENTRAL WATERSHED RESEARCH UNIT

COLUMBIA, MISSOURI

A. T. Hjelmfelt, Jr.[1/] and staff

INTRODUCTION

The Watershed Research Unit in Columbia, Missouri, was organized in 1962. Its research history extends back to 1937, however, with cooperative field-plot studies at McCredie, now called Kingdom City. The role of this unit is to conduct research on soil and water conservation practices on agricultural watersheds in the cornbelt states. The particular subjects studied are watershed hydrology, erosion and sedimentation processes, including reservoir sedimentation, and water quality.

Research sites are located in the deep loess region of southwestern Iowa and the claypan region of north central Missouri. Small plot studies of cropping and tillage effects on soil and water movement are conducted at Kingdom City, Missouri, and small watershed studies at Goodwater Creek, near Centralia, Missouri. Four field-size watersheds near Treynor, Iowa, are utilized for deep loess studies, and four small reservoirs located near Columbia, Missouri, are instrumented for reservoir sedimentation studies. The early Kingdom City studies were summarized by Jamison et al. (1968). The Treynor, Iowa, work was described by Saxton et al. (1971) and Spomer et al. (1980).

2.0 DATA ACQUISITION

Problems associated with data acquisition and actions taken to insure data quality are summarized in Table 1.

2.1 Precipitation. Precipitation is measured at each of the research sites. The requirements vary widely, however. The rapidly responding fields at Treynor, Iowa, need rainfall intensity in small time increments with careful time-correlation to runoff. Slower responding reservoirs and the larger watersheds are less critical in short time precision. The plot studies at Kingdom City deal mainly with event volumes. Larger watershed studies on Goodwater Creek require a dense network of raingages to establish aerial distribution of rainfall.

2.2 Runoff. Runoff is measured at each of the sites. The ability to record sustained low flows and to obtain good definition of storm events dictate use of multiple recording systems. Weirs (v-notch) are used at all watershed and field sites. Calibrated spillways are used on some reservoirs and, where spillway calibration is not feasible, flumes are used. Small flumes are used for plots, small subwatersheds and for terrace pipe drains. Runoff from the plots at Kingdom City is measured volumetrically with only event totals obtained.

At Treynor, Iowa, high sediment loads have caused difficulties. Small, 15+ acre, subwatersheds carry high sediment loads and the land profile flattens near the measurement structures, causing the weirs to silt full. Placing a "turbulence" wall

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about 15 ft upstream of weir, with notch 1.2 ft above weir notch elevation, seems to minimize effect of sediment. Two standard erosion plots were initially fitted with conventional HS-flumes but high sediment concentration deposited 0.2 ft of sediment in the 0.5 ft. throats filling the stilling wells and inlets. Drop-boxes (Johnson et al., 1966) are being used and appear to be working better, but a complete redesign of the outflow collector was required to fit the box.

2.3 Sediment Concentration. Sediment concentration is monitored regularly at all sites except the watersheds at Centralia where only intermittent sampling is underway. Automatic samplers are used except at Kingdom City where average concentrations are obtained from event totals.

Several thousand suspended sediment samples of surface runoff have been collected from the two 80-acre nonconservation watersheds at Treynor, Iowa--by dipping, by automatic pumping, and by hand sampling. Sediment concentrations are routinely in the 100,000 to 250,000 ppm range, so that we have had difficulty with virtually every type of automatic sampler (PS-67, PS-69, the Columbia Sampler, and ISCO). Nearly every feature of the St. Anthony Falls' samplers has been fallible. Power failures on both battery and AC systems have occurred. It has been shown that intake placement is not critical in our region because nearly all material is fine-textured and well-mixed. Plugging from the crop residues and soil is commonplace, however.

Both priming and self-priming pumps are used. Self-priming pumps are desirable, but their placement is critical. Pumps that need priming and utilize flush tanks have presented problems; the tanks collect stream water on the "waste" cycle and accumulate sediment until the pumps cannot move the mixture. This can be alleviated by placing two tanks in series. Long intake pipes from stream to sampler can result in contamination of samples with "flush" water unless adequate purging time has been allowed before sampling. These intake pipes deteriorate with age, develop kinks, and are damaged by rodents.

Timing to obtain samples at proper intervals and to obtain proper sample volumes is also important. Temperature and humidity appear to affect the timing cycles: correct adjustment during fair weather does not mean filling time will be correct during a storm. Event markers have been a problem, and settings are critical. No type of marker has been superior to another. The human element is a very important factor in improperly operating samplers. Constant maintenance is needed, especially in locations where there is a large time lapse between storms. Efficiency could also be improved by standardizing on one type of sampler.

In the final analysis we have found that samples collected manually by field personnel are the most reliable--and that sole reliance on pump samplers can give us no record, or an erroneous record.

Sample comparisons (automatic vs. hand-collected with DH-48 sampler) show that concentrations for comparable times are usually within about 10% of each other; there is no systematic difference. Pump samples, however, are more erratic. Usually this does not affect the accuracy of a storm sediment record more than 10 percent--unless there are no other samples to rely upon for the entire storm.

2.4 Chemical Transport. Concentration of dissolved and adsorbed chemicals in the runoff is monitored using the same sampling equipment as for sediment concentration.

Dissolved components of runoff are separated by passing through 0.45 μm filters. Nitrogen analyses are performed with a Technicon autoanalyzer and those for phosphate with a spectrophotometer using the method of Murphy and Riley (1962). Particle size is analyzed with a Particle Data electronic analyzer which measures the volume of each particle.

Dissolved chemicals in precipitation collected with automated rainfall samplers are monitored at both the Treynor and Kingdom City locations.

2.5 General. Several items of data acquisition are common to each of the groups described separately above. It is important that station records be kept up to date. This insures prompt identification and remedy of station problems. Field personnel should keep supplementary records to aid interpretation of unusual charts and to help evaluate effects of station malfunctions. Supervisors must recognize that field personnel may lack an appreciation for why data must be handled carefully. Boredom and apathy can result in poor quality results.

3.0 DATA QUALITY PROBLEMS

Quality of data and special problems associated with the various measurements are summarized in Table 2.

3.1 Precipitation. Weighing-recording raingages are used at all locations. Charts are changed weekly or after major events. Gages are leveled annually and checked with weights periodically.

The major problem with precipitation measurements results from separate timing for each rainfall and runoff recorder. Small time difference may be significant in analysis of rapidly responding sites.

3.2 Runoff Data. Runoff measurements are based primarily on precalibrated structures such as weirs and flumes. Discharge from two reservoirs is based on the stage-discharge rating for their spillways. This rating is sometimes changed temporarily by debris accumulation which we try to remove after each event. The very high sediment concentrations at Treynor, Iowa, result in silting upstream of the weir and in the approach channel. This may result in underestimation of high flows and overestimation of recession flows. Extreme events on Goodwater Creek near Centralia, Missouri, inundate the flood plain, thus presenting difficult calibration conditions.

Stage is recorded on float- or bubbler-operated FW-1 recorders. Most have 24-hour charts. Accuracy of bubbler-operated gages is usually better than ±0.02'. Dirty contacts and weak batteries can, however, degrade this accuracy. Sediment accumulation over the bubbler orifices can cause erratic behavior, but this can usually be cured by purging the orifice.

3.3 Sediment Concentration. Automatic samplers used to monitor sediment concentration have failed due to electrical and mechanical problems, plugging with sediment, and have given faulty readings resulting from inadequate flushing. Electronically programmed samplers have been susceptible to reprogramming by lightning.

3.4 Chemical Concentration. Chemical concentrations are sampled with the same apparatus used for sediment concentration and so have the same problems.

The best available analytical techniques are used for sample analyses. Greatest sources of error are probably caused by chemical transformations which may occur prior to performing analyses and by lack of representativeness in the samples collected. Precautions taken to minimize transformations are noted in Table 1. For plots at Kingdom City, the total runoff or, for larger events, a fraction of the total is collected. Representative samples for dissolved and sediment-associated chemicals for the total runoff are, thus, easily obtained. However, the representativeness of samples taken during events by automated samplers is uncertain, particularly for sediment-associated chemicals. This uncertainty results from the non-homogeneity of sediments in runoff at the point of sampling and the ability to only sample at a

single point in the runoff stream. The latter is also a source of uncertainty for runoff data collected at the Treynor watersheds.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

Additional research is needed for all measurement involving flows containing heavy sediment concentrations. Previous studies involving staff from this unit were by Saxton and Ruff (1976), Ruff et al. (1977), and Mefford et al. (1979). Floating (movable) intakes for various pumping samplers need to be studied and recommendations made. Perhaps this study could be done at St. Anthony Falls' lab, if field conditions (trash, etc.) could be simulated. Rausch and Haden (1974) have worked on sampler development.

Accurate definition of the timing of events and correlation of times among various recording devices are necessary. One study in this office has addressed the problem of timing (Haden, 1976).

Data reduction is a large and continuing concern in any unit with a large number of recording gages. A reliable and relatively inexpensive electronic data acquisition system is needed.

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Table 1. Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Recording raingages	Clock stoppage, dry pens, leveling, calibration	Frequent inspection & maintenance
	Ice and snow	Antifreeze, remove orifice funnels, volumetric snow measurement
	Leaking, broken or rusted buckets	Replace at 5-yr. intervals
Watershed raingage network	Access to gage	Place near public right-of-ways, and protect from vandals.
2.2 Runoff/streamflow:		
Rate of flow	Sediment accumulation behind weir and within flumes	Frequent flush out. Use drop box weir. Mechanical removal. Change flume capacity.
	Plugging of stilling well intakes	Multiple intakes. Cut slots in stilling wells. Use continuous flushing system.
	Clock stoppage, dry pens, calibration	Frequent maintenance
	Ice on weirs and flumes	Heat tape, heat lamps
	Frost and ice in stilling well and gage house	Bubble gage with oil on surface of stilling well. Use heat lamps.
	Calibration of flow control element	Use precalibrated structures and verify calibration.
Volume of runoff	Debris accumulation	Frequent maintenance
	Leaky collection tank	Periodic maintenance
2.3 Sedimentation:		
Sediment sampling	Getting a representative sample	Use equal transit rate procedure, or sample through weir nap.
	Defining concentration through event	Automatic sampling
	Not representative sample	Adjust sample cycle time to insure proper flushing. Change location or type of intake, keep intake short as possible.
	Power failure	Use battery backup
	Silting flush tank	Use two tanks in series
	Sample confusion	Standardize samplers
	Nonrepresentative sample from tanks	Stir sediment-laden water more thoroughly
2.4 Water Quality:		
Chemical concentrations	Samples obtained from sediment samples, thus same problems	Same as for sediment samples
	Chemical transformation	Process soon after event
	Inconsistent procedures	Standardize analytical procedures
Rainfall sampling	Airborne contamination	Automatic opening and closing raingage
	Sensitivity of analysis	Minimize contamination

Table 2. Data Quality Evaluation

Description of current stations	Number of stations	Estimate of data quality[1/]	Special problems and comments
3.1 Precipitation:			
Non-recording gages	3	Good	Winter season precipitation
Recording gages	44	Good - excellent	Data reduction labor intensive
3.2 Runoff/Streamflow:			
V-notch weirs	13	Poor - good	Calibration and data reduction
Flumes	15	Poor - good	Sedimentation
Spillways	3	Poor - fair	Debris accumulation, lack of sensitivity.
3.3 Sedimentation:			
P.S. 66	2	Good	Large power requirement
P.S. 67	2	Poor	Mechanical and electrical problems
P.S. 69	4	Fair	Mechanical and electrical problems
Columbia	8	Poor - good	Heavy sediment not adequately sampled, mechanical and electrical problems
Isco	9	Poor - good	Heavy sediment not adequately sampled, electrical sensitivity
3.4 Water Quality:			
Chemical concentration	54	Fair - good	Past analytical procedure inadequate

[1/] Excellent = ± 5% Fair = ± 20%

Good = ± 10% Poor = > 20%

REPORT ON QUALITY OF WATERSHED DATA
USDA SEDIMENTATION LABORATORY

by

N. L. Coleman and Staff

INTRODUCTION

The USDA Sedimentation Laboratory is a National Laboratory with an extremely diverse program of fundamental research into all aspects of soil erosion and sediment production, the transport of sediment by streams, and the deposition of sediment in stream channels, flood plains, and reservoirs. Experiments to define the interaction of agricultural chemicals with water and sediment are also carried out.

In addition to a large building containing flumes, hydraulic model basins, and other capital research facilities, the Sedimentation Laboratory also maintains four instrumented Research Watersheds. Here the general fundamental results obtained from laboratory research can be studied further in the field, and hydrologic measurements of streamflow, sediment transport, and related phenomena can be made. These measurements are necessary for the formulation and verification of streamflow, sediment transport, and watershed response models, and to define watershed responses to various changes in land use and cropping practices.

The watersheds maintained by the Sedimentation Laboratory are the Pigeon Roost Research Watershed, the Goodwin Creek Research Watershed, the Unit Source Watershed Complex at the North Mississippi Branch Experiment Station, and the Flatland Watershed Complex in the Mississippi Alluvial Plain near Clarksdale and Glen Allan, Mississippi.

The Pigeon Roost Research Watershed is 117 square miles in area, and was approximately 21 percent in cultivated land, 20 percent in pasture, and 59 percent in woodland and other nonintensive use in 1973, which was the year of latest land use survey. The drainage net consists of Pigeon Roost and Cuffawa Creeks, with their numerous tributaries. Thirty-one raingauges are located in this watershed, and twelve gauging stations are located stratigically throughout the drainage net. With the exception of one station where a sheet pile weir has been installed, these gauging stations are located on uncontrolled alluvial channel reaches.

The Goodwin Creek Research Watershed is 8.3 square miles in area, and is approximately 35 percent in cultivated land, 30 percent in pasture, and 35 percent in woodland and other nonintensive use. The drainage net consists of Goodwin Creek, with a number of tributaries. Thirty-one raingauges are located in this watershed, and 14 gauging stations are located on Goodwin Creek and its tributaries. At all these gauging stations, critical flow measuring flumes (Gwinn, 1970; Smith et al., 1981) have been constructed.

The Unit Source Watershed Complex consists of a 50 acre tract divided into a number of small plots and watersheds that are maintained under a variety of conservation tillage practices. Precipitation measurements are made with a single raingauge located in the tract. Each of the 3 small watersheds is equipped with its own Parshall flume for runoff measurement.

The Flatlands Research Watershed Complex consists of two sites. The first site, near Clarksdale, Mississippi has four plots in two similar and adjacent pairs, so as to allow comparison of agricultural plot behavior under different

treatments. One pair on the McWilliams farm is composed of plots of 38 and 42 acres, respectively, with one raingauge serving for precipitation measurement and with a Parshall flume measuring the runoff from each plot. The second pair, about 6 miles away from the first, is composed of plots of 6 acres each, again with one raingauge and two Parshall flumes. The McWilliams site also includes a pond of about 4 acres extent, equipped with a 90-degree V-notch weir for outflow measurement.

At the Glen Allan site, a 640 acre tract is instrumented with 1 raingauge and with a recorder at the entrance of a culvert at the outlet of drainage from the tract. A standard culvert discharge equation (Carter, 1957) is used to compute runoff from this tract. An upper part of this tract, comprising 100 acres, is separated by a road from the lower part. Runoff from this segment is monitored by another culvert that has been equipped with a commercially available electromagnetic discharge meter. Also at Glen Allan are a pair of graded plots instrumented with one raingauge and with Parshall flumes for measuring runoff.

DATA ACQUISITION

In choosing components for a watershed data acquisition system, emphasis can be placed on the use of manpower for making measurements, which requires that a reasonable number of personnel be distributed over the watershed during storms, or upon the use of automated equipment. In theory, the automated equipment is supposed to reduce the manpower requirements for operating a watershed effectively. In practice this is not the case, since the successful operation of the automated equipment requires the constant activity of a large team of maintenance personnel, including hydraulic engineering technicians and electronics specialists, throughout the watershed both between and during storm events. In addition, the experience of NASA and other agencies that have had a record of success with remotely operated environmental sensing equipment shows that success is only achieved by the use of extremely redundant systems that are capable of adjusting to the inevitable failure of system components. The financial support for this level of redundancy is generally unavailable to watershed researchers. Evidently, there is little difference in actual manpower requirements between manned and automated systems, and, on the usual level of financial support for watershed research, little economic difference either. Table 1 summarizes the major categories of problems and solutions that have been encountered by the USDA Sedimentation Laboratory Staff in its experience in operating the four watershed research facilities that were described above.

Table 1. Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
1.1 Precipitation:		
Standard recording raingauge	Mechanical failures	Annual or semiannual maintenance of gear trains, etc.
	Clock failures	Replacement; regular battery change on electric clocks.

Table 1. (Cont'd) Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
	Inking problems	Replace standard slot pens with bucket pens; change charts after every rain
Automatic recording raingauge	Few problems	Serviced weekly or within 24 hours after storms; volume standards checked after each storm; seasonal maintenance and calibration
1.2 Runoff/Streamflows:		
A-35 Stage recorders	Mechanical linkage problems	Weekly maintenance; annual or semiannual tapedowns from fixed reference for zero check
	Clock failure	Replacement
	Inking problems	Replacement of faulty pens
FW-1 Stage recorders	Similar problems to above	Similar solutions to above
	Cam cusp zero error	Set zero on chart at 1-foot line
Parshall flumes and all super-critical flow discharge measuring devices	Submergence error at high discharges	Installation of dual stage measuring systems to use headwater/tailwater type calibrations
	Approach flow misalignment	Eliminate misalignment during installation; calibrate in place
	Sediment deposition in device during high flows	Install smaller capacity structure to insure higher flow velocities that will prevent deposition
	Sediment deposition during recessions	Clean structure between storms

Table 1. (Cont'd) Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
	Questionable original calibration due to deviation of structure from specifications	Calibrate in place after installation
1.3 Sedimentation:		
All types of pump samplers	Measured concentration not representative of flow cross-section concentration due to incorrect intake placement	No known solution; the representative placement point for the sampler intake has never been discovered, and may not exist
	Plugging due to trash	Installation of automatic air backflush systems; constant maintenance
Single stage samplers	Plugging due to trash or insects	Regular maintenance
Silt boxes	Overflow; trashing	Clearing or cleaning after every runoff event
1.4 Water quality		
Bacteriological concentration	Concentration errors	Make counts very soon after sampling
Chemical properties of water	Contamination errors	Use chemically inert sampling equipment
1.5 Radio-telemetry systems, all types:		
	Transmission failures from lightning	Install lightning arrestors; gas ionization tubes, etc.; install lightning rods and grounds
	Transmission failure from interference or component failure	None possible

Table 1. (Cont'd) Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
	Power failure	Install back-up battery systems for short-period use

Examination of Table 1 indicates that there is no mystery about the operation of present state-of-the-art watershed instrumentation; any person of average intellect can discern what is needed to solve all solvable problems through a combination of common sense and attentive reading of the instruction manuals for the commercial equipment involved. It is equally evident that there is a class of problems regarding watershed data measurement that contains problems not amenable to solution.

DATA QUALITY EVALUATION

The qualities of different kinds of watershed data can be widely different. For example, standard recording raingauge data that has been collected by the Sedimentation Laboratory Staff over a period of some 20 years is generally regarded as good, although it is recognized that special problems can arise when raingauges are affected by wind and other factors. Pumping sampler data is usually very representative of cross-section concentrations of material less than 0.062 mm in diameter because this material will be quite uniformly distributed in a channel or gauging structure section, so that it does not matter where the sampler intake device is located. For material larger than 0.062 mm in diameter, pumping sampler error increases rapidly with particle size. For adequate sampling of sand-sized materials, the problem of where to locate a pumping sampler nozzle in a flow cross section in order to get a representative concentration determination is still open to research, and may be one of those problems with no answer.

Some estimates of data quality for the various kinds of data collected in the four watershed research facilities operated by the USDA Sedimentation Laboratory are summarized in Table 2. For the four research watershed complexes operated by

Table 2. Watershed Data Quality Evaluation

Description of stations	No. of stations	Estimate of data quality 1/	Special problems and comments
2.1 Precipitation:			
Standard recording raingauges	75	Good to excellent	Occasional electric clock failure
Pit raingauge	1	Unknown	Newly installed

1/ Excellent ±5%; Good ±10%; Fair ±20%; Poor greater than 20%

2/ Varies with specific program requirements

Table 2. (Cont'd) Watershed Data Quality Evaluation

Description of stations	No. of stations	Estimate of data quality[1/]	Special problems and comments
2.2 Runoff/Streamflow:			
Rated alluvial sections with stage recorders	12	Excellent to fair	Quality depends on whether sections are rated by wading discharge measurements or measurements from cable rigs
Parshall flumes and all super-critical flow discharge measuring devices	27	Excellent to good	Best when calibrated in place. Must be kept clear of sediment deposits
Various types of recorders used with above	27	Excellent to good	Float wells subject to sedimentation - must be cleaned regularly
2.3 Sedimentation:			
All types of pump samplers	33	Excellent to poor	Excellent for fine material; fair to poor for sands; useless for material coarser than coarse sand
Single stage samplers	5	Good to poor	Depends on sediment size
2.4 Water quality:			
Bacteriological concentrations	Varies[2/]	Good	Care must be taken to avoid sample contamination
Chemical properties of water	Varies[2/]	Good	Need chemically inert samplers and containers, and elementary guards against contamination
2.5 Radio-telemetry systems, all types:			
	13	Good	Correct parity checks on transmissions insures error-free data sending and receiving. Constant maintenance or redundancy needed

the USDA Sedimentation Laboratory, only the most general kind of summary could be put in Table 2, because of the wide variety of equipment and installations used, and the many different particular situations that have been encountered.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

Watershed measurements of total sediment discharge are in most instances virtually impossible to make. In a few cases, like the one described by Miller and Bowie (1965), an overfall structure can be installed to allow the complete sampling of the flow for sediment through a free nappe. This is an effective way to obtain total sediment load studies, but in many watershed studies the presence of such structures imposes an undesired grade control, so that channel response to different watershed variables cannot be investigated. Research should be directed toward the goal of greater understanding of the ways in which sediment moves through normal alluvial channel sections, in the hope that this will provide more adequate ways of calculating total sediment load based on possible suspended sediment measuring techniques. The prospect for progress in this area is, unfortunately, not very favorable.

In situations where grade control can be tolerated, it is often still not feasible to use free overfall type gauging structures if stream gradients are relatively flat, as the structures are submerged at the high flows which are carrying the greatest amount of sediment. Frequently, supercritical flow measuring structures are used in these circumstances for discharge measurement, and a pumping sampler is installed at the structure in an effort to get a concurrent determination of the sediment discharge concentration so that sediment loads can be calculated. As indicated in Table 2, this system is quite adequate for measuring the uniformly distributed very fine sediment. However, research is needed to determine the most representative placement of the pumping sampler intake for measuring sand concentrations, if such a placement exists. Since the critical flow structures generally accelerate the flow enough to throw all but the very coarsest material into suspension, it is quite possible that improved placement of pumping sampler intakes, together with advanced design of the intakes themselves, may result in significant improvement in the quality of sand transport measurements.

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REPORT ON QUALITY OF DATA FROM THE DEE CREEK WATERSHED, LINCOLN, NEBRASKA

by

J. S. Schepers and G. E. Schuman

INTRODUCTION

The mission of the Soil and Water Conservation Research Unit is to study and develop improved methods of soil, water, and crop management that will maintain or improve productivity and also conserve soil, water and energy resources. Several aspects of this mission are to:

Evaluate the quality and quantity of runoff water from an agricultural watershed and relate to cropping and fertilization practices.

Develop management practices that reduce sedimentation and control erosion while conserving water.

The Dee Creek study was initiated in 1974 to compare the characteristics of runoff from a relatively large agricultural watershed (2200 ha) to those of smaller, monoculture projects (10-60 ha) previously studied and ongoing watershed projects, and also to larger statewide water quality evaluations. The watershed was representative of the highly productive dryland agricultural area with about two-thirds of the land having adequate conservation practices. An annual survey of all producers was conducted to establish hectarage of crops grown, fertilizer and herbicide application, and crop yields (Schepers et al. 1980).

2.0 DATA ACQUISITION PROGRAM

2.1 Precipitation: The precipitation recording network on the Dee Creek Watershed was primarily established to measure spacial variability of rainfall during the period when the soil was not frozen. Snowfall typically comprised about 10% of the 70 cm average annual precipitation. Precipitation resulting in runoff was usually due to thunderstorms which were quite variable in amount and intensity.

The original weighing rain gage network was established in 1974 with a tipping bucket gage added in 1980 to better evaluate contamination of rainfall samples with bird feces. This gage was coupled with an ISCO automatic sampler to collect samples at 0.25 cm increments of rainfall (Table 1).

2.2 Runoff/Streamflow/Groundwater: Runoff collection was initiated when the stream flow level reached 6.0 cm above the low and nearly continuous baseflow. Sampling continued at 20 minute intervals until the baseflow level was approached. Runoff over the weir constructed of bridge piles was calculated using a calibration curve for a USGS gaging station located 100 meters downstream.

2.3 Sedimentation: The stream was determined to have no appreciable bed load, thus sediment carried by the stream was largely suspended silt and clay. Little deposition or scouring within the stream channel was apparent.

Table 1. DATA ACQUISITION SYSTEM

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Watershed raingage network	Ice	Antifreeze used in gages
	Clock failures and mechanical problems	Annual maintenance and calibration
	Spacial variability	Installed additional gages
	Bird contamination of water	Installed antiroosting wires
	Variation in chemical concentrations	Documented quality changes by adapted tipping bucket gage to automatic water sampler
2.2 Runoff/Streamflow/Groundwater:		
Streamflow gaging station	Freezing stilling well	Added anti-freeze in winter
	Trash on weir and backed up water below weir	Eliminated beavers
	Erosion behind weir	Installed gabions
Water samplers	Frozen PS-69 samplers	Hand sampled or used ISCO sampler
	Intermittent sampler controller failure	Have second controller available and used backup ISCO sampler
2.3 Sedimentation:		
Streamflow gaging station	Sediment accumulated in stilling well	Periodic flushing of dual entry stilling well
2.4 Water Quality:		
Chemical concentrations	Occasionally insufficient sediment	Alternate samples analyzed for TKN and total P
	Poisoning (unresponsive after a short time) of continuous monitoring dissolved oxygen probe	Resorted to periodic manual samples
Bacteriological concentrations	Variability between weekly samples	Document lifestock feeding operations and home sewage systems

2.4 Water Quality: Runoff samples were analyzed for soluble and sediment associated nitrogen (N) and phosphorus (P), chemical oxygen demand, pH, titratable alkalinity, and solution sodium and potassium (Schepers et al. 1980). Sediment contained in the samples collected either early or late during a runoff event frequently was not adequate to determine both sediment N and sediment P. In such cases, alternate samples were used for these analyses.

Bacteriological samples were collected at weekly intervals from the baseflow with limited sampling during runoff events. Total and fecal coliforms were determined on each sample.

3.0 DATA QUALITY PROBLEMS

3.1 Precipitation: The major problem encountered was with the spring-wound clocks. Spacial allocation of the land area represented by each gage had to be adjusted each time a gage failed which required considerable time. Reliable operation was achieved by annual maintenance. Other problems encountered and action taken are noted in Table 2.

3.2 Runoff/Streamflow/Groundwater: Few problems were encountered with the operation of the gaging equipment and weir except during a 3-4 day period in the spring when snow melted and ice would temporarily collect in front of the weir. Under these conditions, flow rates were usually relatively small and ISCO samplers or hand samplers were used to avoid damaging the PS-69 samplers due to the intermittent freezing conditions.

3.3 Sedimentation: The only problem encountered was after four years of operation when the stilling well would not allow the zeroing of the water-stage recorders. The problem was remedied by removing the accumulated sediment from the bottom of the stilling well.

3.4 Water Quality: During the first year of the study, a continuous monitoring dissolved oxygen probe was used in the stream, however, its unsatisfactory operation was overcome by performing these analyses on baseflow samples collected weekly. Bacteriological sampling was discontinued after 1976 because it was determined that the wide variations in coliform counts were due to natural conditions rather than feedlot runoff or home sewage systems that were present in the watershed.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

1. Develop small, portable flow recorders using microprocessors to provide the accuracy of traditional float type recorders. This equipment could record the data on magnetic tape and the microprocessor could also collect data from and/or control other climatologic equipment.

2. Develop and provide technical assistance in the use of solar power supplies to operate equipment at remote locations.

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Table 2. DATA QUALITY EVALUATION

Description of current stations	Number of stations	Estimate of data quality[1/]	Special problems and comments
3.1 Precipitation:			
Weighing gages	9	Good - rainfall Fair - snow	Snow catch difficult
Tipping bucket	1	Good	Compares well with weighing gage
3.2 Runoff/Streamflow/Groundwater:			
Stream weir	1	Good @ low-med flow Fair @ high flow	Insufficient high flow events documented and calibrated by USGS
3.3 Sedimentation:			
P.S. 69 automatic pumping sampler	1 (1 backup)	Good	Compared well with hand samples
ISCO portable pumping sampler	1	Good	Provides quick and easy backup sampler
3.4 Water Quality:			
Chemical concentrations	1	Good - excellent	Used standard methods
Bacteriological concentrations	1	Good	Variability between sampling dates attribute to home sewage systems and natural variability

[1/] Excellent = ± 5%
Good = ± 10%
Fair = ± 20%
Poor = <> 20%

QUALITY OF WATERSHED DATA AT THE NORTH APPALACHIAN EXPERIMENTAL WATERSHED, COSHOCTON, OHIO

T. J. Harlukowicz, J. V. Bonta, W. M. Edwards, and C. R. Amerman[1/]

INTRODUCTION

In 1935, the U.S. Department of Agriculture Soil Conservation Service established a research station near Coshocton, Ohio to study water, land use, crops and erosion on individual farm fields and on entire watersheds. The station was transferred to the Agricultural Research Service, U.S. Department of Agriculture in January 1954. What is now the North Appalachian Experimental Watershed (NAEW) includes a 1047-acre land block controlled by the U.S. Department of Agriculture. These properties typify much of the agricultural land in the unglaciated Allegheny Plateau. Land management is consistent with local practices and is applied to 470 acres of cropland, 270 acres of permanent grassland, and 307 acres of woodland. Watersheds range from 1 to 303 acres. Generally, smaller catchments are units of cropping systems and are less than 10 acres, mostly of one major soil type and with land slope of one major class.

The present mission of the North Appalachian Experimental Watershed is to develop procedures for predicting the movement of water, sediment, and chemical constituents in the landscape and to develop and evaluate management systems as to their effects upon such movement. Research at the center located in LRA 124, Land Resource Region N, serves directly the agricultural, industrial, rural and urban water information needs of the hill land of southeastern Ohio, western Pennsylvania, western West Virginia, and portions of eastern Kentucky and southern Indiana. Current specific thrusts are (1) to develop methods of predicting runoff from and the water balance within watersheds in the North Appalachian Region, (2) to define the hydrology and water quality of watersheds subjected to surface mining, (3) to define the effects of fertility and pasture management practices upon hydrology and water quality and (4) to develop new and improved methods of managing waste and waste waters from feedlots.

The diversity of the research program at Coshocton and the environmental situations which must be accomodated in accomplishing the research objectives requires the maintenance of an extensive data acquisition system consisting of numerous components. An inventory of the components, problem situations normally associated with each, and actions required to insure data quality are presented in Table 1. Generally, a problem is either persistent and due to an inherent characteristic of a component, or is intermittent and due to mechanical malfunction, human error, or adverse seasonal or atypical climatologic impacts. In the latter case, preventive measures can be taken to eliminate or minimize the impact on data quality. Details of the data aquisition components of the Coshocton Station and the quality of data from each are discussed in the following sections.

1/ Research Hydraulic Engineers, Soil Scientist, and Research Hydraulic Engineer, USDA-ARS, North Appalachian Experimental Watershed, Coshocton, Ohio 43812, respectively.

Table 1. Data Acquisition System

Instrument Description	Problem Situations	Action taken to insure data quality
A. Precipitation		
Standard recording raingage	Clock failures	Frequent service checks (twice weekly)
	Chart expansion and contraction due to extreme humidity changes	No action
	Time synchronization	Obtain proper reference time from Western Union prior to service
	Mechanical problems	Regular maintenance and calibration checks
	Ice	No action
	Deficient catch	No action taken since shield vs unshielded vs pit gage not consistent
Pit Gage	Blowing snow	Data not reported
Snow Courses	Sample representation	On-site mapping of such special features as large drifts on small watersheds
B. Runoff/Streamflow/ Groundwater		
Streamflow gaging network	Sediment deposition in weir approach	Frequent cleaning
	Severe icing	Enclosures and heaters installed
	Recorder malfunctions	Frequent servicing
	Clogged intakes to stilling well	Frequent servicing
Spring development	Pulsations of discharge due to siphoning	Re-installation
Observation well network	Inadequate data for aquifers with rapid response time	None

Table 1. Cont'd.

Instrument Description	Problem Situations	Action taken to insure data quality
Plots with drop-box weirs	Sediment trap fills with sediment	Frequent cleaning
	Box can catch large amounts of sediment over long periods	Frequent cleaning
	Departure of drop-box rating from "universal" rating	Lab calibration
C. Sedimentation		
Coshocton wheel	Leaks through wheel surface	Epoxy paint for rust-proofing
	Inconsistent sample splitting	Eliminate splitter by using single large sample container
	Ice forming on flume floor and wheel	Insulated and heated shelters installed
	Sediment deposition in flume approach	Shovel sediment into buckets after storm and weigh
Coshocton vane	Stratified sampling	Move sample pick-up point to plunge pool below weir
Plot sampling	Sump fills with sediment	Provide large sump (No money for better pumps)
Watershed sampling using drop-box weir	Deposition near intake in drop-box weir	Move intake into very turbulent water and allow to move so rocks and debris will not damage it
D. Water Quality		
Precipitation water quality	Contamination from suspended particles prior to precipitation	Wet and dry samplers operated in unison
		Proper insulation and sealing of wet samplers during dry periods
	Sampling variability	Rigorous conformance to standard procedures

DATA AQUISITION PROGRAM

2.1 Precipitation

Precipitation data collected at Coshocton are derived from twelve weighing, unshielded, recording raingages, one weighing, dual recording gage and one recently installed pit gage (non-recording). Three additional dual recording gages are serviced off the station at watersheds being studied for the impact of surface mining on watershed hydrology. All gages have been installed in conformance with procedures documented by Brakensiek et al (1979). Breakpoint data (time and accumulation) are manually read from the charts and tabulated for keypunching and subsequent automatic processing. A formula derived by Hamon (1972) is applied to dual raingage data to compute precipitation corrected for catch deficiencies under windy conditions. Summer precipitation in the North Appalachian Region comes predominantly from convectional storms. These storms are of high intensity, but of short duration over small areas. Winter precipitation results from cyclonic storms and frontal systems and is of lower intensity, but of longer duration and over larger areas. On the average, monthly precipitation is greatest from March through July. The variability of the high intensity storms requires that high resolution charts and timer mechanisms be used to obtain accurate records of precipitation intensities. Current station policy is to use 6-hour charts at the lysimeter sites, 24-hour charts at the dual recording gages and 12-hour charts at all but two of the remaining gages. Weekly charts are used at the two remaining gages primarily to obtain total catches and to facilitate identifying times of occurrence at the other gages. A two-man crew services the raingage network twice each week and replaces charts once a week or after large events. In 95% of the cases, no time corrections need be applied to the record. When timing problems occur persistently, timing mechanisms are replaced. Proper time synchronization of all gages is checked each servicing and established by a call to Western Union by the serviceman to obtain the correct reference time prior to servicing. Volumetric calibrations are routinely done to verify the reliability of the weighing mechanism.

Snow depth accumulation averages only about 20 inches per year or about 5% of total precipitation. Accordingly, measurement of snowfall has not received a high priority. In recent years, sparse snow courses have been laid out on small (1 to 8 acre) watersheds. Measurements for a watershed are recorded on a map on which the observer also shows the areal extent of any drifts or clear-blown areas. A sampling program has not been devised for larger watersheds.

2.2 Runoff/Stream Flow

Broad crested V-notch weirs, H-flumes, a Columbus deep notch weir, and drop-box weirs are the principal flow measuring devices used to gage stream flow at Coshocton, Ohio. Table 1, Section A. lists the inventory of stream gaging structures at the NAEW.

Regardless of device, FW-1 recorders with spring-wound clocks are used to record stage as a function of time. Each stage-monitoring station is visited at least twice a week at which time clocks are wound and the devices checked for debris or obstructions. Each station is also visited within 24 hours after a significant storm at which time charts are changed. During storm-free periods, charts are changed once a week.

Runoff from the NAEW's larger watersheds is gaged by several broad crested weirs and one Columbus deep notch. Each site is equipped with separate FW-1's to record stages in the high and low ranges. High stage instruments are equipped with

24-hour gears to provide enhanced resolution of short-duration and high-intensity storm related runoff. Low flow instruments are equipped with 192-hour gears on which to record smaller events and base flow. Mefford, et al (1979) have shown that stage-discharge curves for the broad crested weir ratings are stable, provided certain approach conditions are maintained. It has been the experience of the NAEW field crew that the approaches to these structures need be cleaned twice yearly for watersheds with a mixture of cropland and woods. A wooded watershed requires a cleaning once every two years. The criteria that have been used for scheduling maintenance are that the stream bed is within 1 foot of the bottom of the V-notch and/or large shoals are within 6-8 inches of the stilling well intake. Because of limited resources, it has not been possible to check ratings before and after approach servicing or to quantify the pre- and post-cleaning approach configuration. When intakes of the access pipes to the stilling well are in contact with bottom sediments, the lines are backflushed to prevent accumulation of material in the pipe.

The 40-year old Columbus deep-notch weir was field-rated using vane-type current meters during the earlier years. It's face has spalled somewhat and further rating checks will be made as runoff events of several magnitudes occur.

Drop-box weirs are being used to measure runoff from watersheds subjected to surface mining. Each installation is equipped with high and low flow recording instruments which have been fitted with mechanical devices that mark the times of occurrence of water-quality sampling and activation of the high-flow recording instrument. Because sediment passes directly over and settles into the intake to the stilling well, sediment traps have been installed between the intake and the access pipe to the stilling well. Servicing of this element of the data acquisition system depends on the duration, intensity and volume of runoff. Generally, access pipes must be backflushed and sediment traps must be cleaned after large storm events and after prolonged periods of moderate flow. Proper operation of these gaging structures also requires strict adherence to maintaining acceptable approach conditions. It has been the experience of the research staff and field personnel that compliance with the established criteria are not possible during periods of active mining and initial reclamation. The volume of sediment deposited after most storms of moderate intensity and volume is sufficient to require too frequent and costly restoration of approach conditions. The impact of this restriction is discussed in Section 3.2. A modified and scaled down version of the same device is currently being used to gage runoff from natural precipitation plots and some rainfall simulator plots on reclaimed land. The modification consists of the removal of the upper high flow section. A sediment trap beneath the remaining V-notch section catches sediment, preventing its entry into the intake pipe and stilling well.

Although the weirs are supposed to have a "universal" rating equation, departures occur below about .2 of the depth of the weir, and also at higher flows. Each plot weir has been individually rated for flows up to .3 cfs.

H flumes are the third major type of flow measuring device used at Coshocton. These devices are installed at the outlets of 1-7 acre watersheds. H flumes do not pass sediments well, and manual removal of sediments, deposited from moderate to large storm events on cropped areas are common.

The station is equipped with only limited groundwater monitoring facilities. Groundwater stage is measured at one site by an FW-1 recorder. Monthly measurements at ten additional observation wells are made manually. Discharge from springs is measured using FW-1's in conjunction with 90° sharp-crested, V-notch weirs or with H-S flumes. Routine service calls to these sites are made weekly.

2.3 Sediment Concentration

Sediment concentrations in runoff from station watersheds are measured by two techniques. On the small watersheds, where flow is measured by H flumes, the Coshocton wheel is used to sample the flow. For larger watersheds, where flow is measured with a broad crested or Columbus deep-notch weir, the sample is collected by the rotating vane sampler (Edwards et al., 1976).

The Coshocton wheel, as used in a side-mount position at the NAEW, catches about 1/500 of the total runoff coming through the flume in each event. Recent reports have shown that a similar center-mounted Coshocton type wheel failed to give representative samples, but as shown in Figure 1, the NAEW version of the Coshocton wheel seems adequate. Runoff amounts for these 25 events, as measured at a watershed during one year, ranged from less than 0.01 to more than 1.16 inches with peak stages in the 2.5 foot H flume up to 1.43 feet.

A major problem with sampling for sediment delivery through the H flumes lies with splitting the sample in the field to obtain a good subsample for determination of concentration. At most small watersheds, data are obtained by storing the samples in two 20-gallon garbage cans. The wheel delivers directly into the first can which overflows through a 1:10 V-notch splitter into the second can. The 1:10 splitter is not consistently accurate and the calculation of concentration in the second can involves a ten-fold multiplication of the error or failure of the split ratio to be 1:10. In recent years the sample holding system at several watersheds has been changed to a single 200+ gallon tank that will hold the entire sample for all storms yet encountered.

The Coshocton vane sampler, used at the larger weirs, also collects a single composite sample for each event. This sampler, however, uses an electric pump to deliver a constant flow to the proportioning sampler. The pickup point is in the turbulent pool below the weir notch where any sediments fine enough to traverse the pool above the weir are certainly in suspension. Figure 2 shows how consistently the vane sampler performs under NAEW conditions.

The major source of error in removing analysis samples from the large collection tanks lies in the difficulty in getting a perfect subsample.

Sediment concentration samples from surface mined disturbed watersheds, natural precipitation plots, and rainfall simulution plots are of both the composite and discrete type.

A sampler below a small drop-box weir on a plot catches all the flow through the weir for a specified proportion of the time (e.g. 1 second out of 30 seconds). The sample is proportional and consists of bedload as well as suspended load. Samples are pumped into 55-gallon drums in tandem. The coarse material is deposited in the sumps. The total sediment from the sump is collected for dry weight determination, and the drums in tandem are each agitated and a sample obtained with a 2" ID aluminum tube, which traverses the entire profile in the drum.

The plots are sampled when a period of no rain is forecast long enough to allow sampling of all plots.

As operational checks, the samplers are operated during plot servicing, the sampler thresholds are checked, and diversion times are measured with a stop watch and are recorded. At the surface mined watersheds, samples are collected with a Chickasha sediment sampler, and with an ISCO sampler. The screened intakes for each sampler are located in the box part of the drop-box weir, but in different locations. At one site, the intake is located beneath the chute and on the downstream side of the box wall.

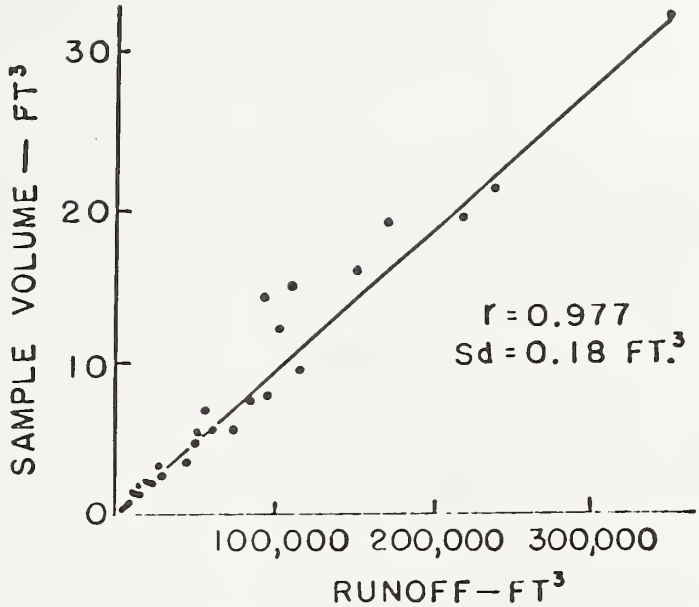

FIGURE 1. Coshocton Wheel performance at Flume 118 during 1975

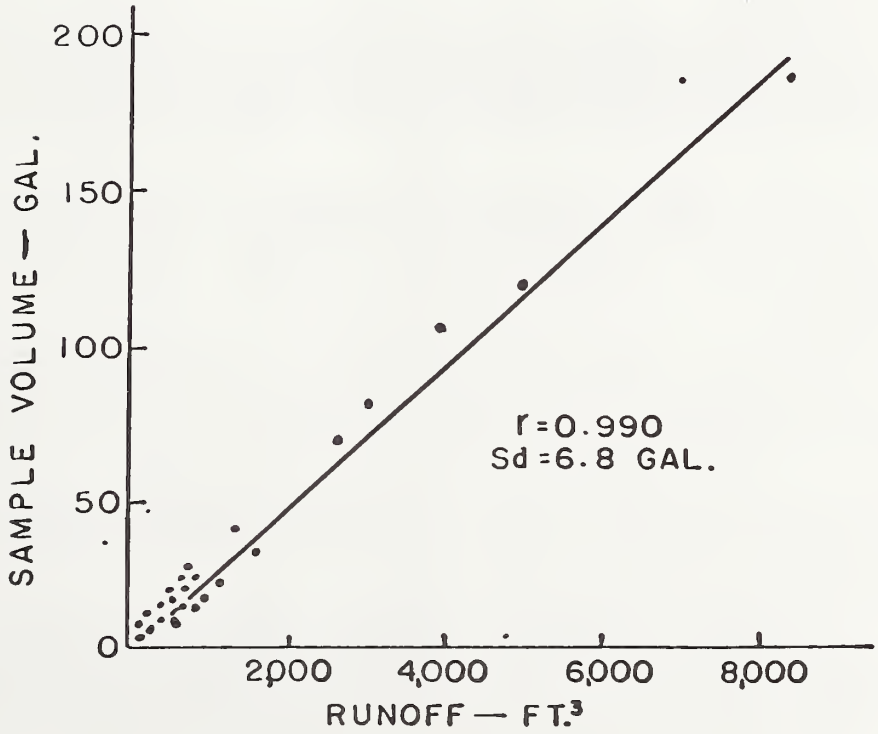

FIGURE 2. Vane sampler performance at Coshocton Weir 182 during 1975.

At the second site, the intake is L-shaped and pivots in the center of the box. The samples are collected every ten minutes. Two ISCO's have been connected electronically to increase the capacity of the sampler (56 samples instead of 28). The ISCO sampler had to be modified to allow sampling of large sediment concentration by enlarging the holes in the tray.

2.4 Chemical Concentration

Samples of surface runoff for chemical analysis are taken from the same sample collections as those used for sediment concentration. When a sampling site is to yield samples for chemical analysis, the sample collecting tank is refrigerated to inhibit chemical transformations. Subsurface flow is sampled weekly at springs, which show much less sampling variability than do surface stations.

The laboratory equipment used for the chemical analyses, which includes a Technicon autoanalyzer, a total carbon analyzer, and an atomic absorption spectrophotometer, and the procedures used for the wet chemical analyses are widely accepted as state-of-the-art and standard methods.

EVALUATION OF DATA QUALITY

3.1 Precipitation

Total precipitation, and the variation of precipitation intensities are standard inputs. The quality of the Coshocton precipitation data is affected by three factors. The first is the inherent characteristic of standard recording rain gages to undercatch precipitation.

The work of Rodda (1967) in England and others has shown that a rain gage exposed to the air stream will undercatch true ground precipitation at the site. The amount of undercatch is related to wind speed and is greater for snow and misty rain. At the NAEW, the undercatch amounted to 6% for rain, 27% for snow and mixed snow and rain, and an average of 9% for total precipitation (McGuinness, 1966).

Shields such as the Nipher and Alter designs have been used for years especially in windy locations. In side by side comparisons at Coshocton, shielded gages caught more rain than similarly exposed unshielded gages but caught less than a pit gage. A proposed system to estimate true ground catch from the relationship between shielded and unshielded gages has been installed at the NAEW, but has not been extensively tested.

Shielding was ineffective for snowfall catch. Currently, the most accurate measure of snow may be the use of snow courses. The errors inherent in snow course measurements can be quite large, but are still smaller than rain gage measurements of snowfall.

In judging rain gages for accuracy, those with average to well protected exposures were considered to undercatch by less than 10% and were rated as good. The more exposed and windier gage sites would probably undercatch by more than 10% and were rated as fair.

A second, and somewhat more controllable factor, is the mechanical performance of a rain gage, independently and in conjunction with other rain gages in the data acquisition network. Errors or losses of record due to mechanical malfunctions (viz. time drifts, clock stoppages, inaccurate weight measurements) are minimized or eliminated by regular and frequent servicing of the instrument and unscheduled service checks

after large precipitation events. Nevertheless, corrections to field records are necessary from time-to-time due to timing errors. Instruments that repeatedly experience time drifts or record erroneous weight measurements are replaced, and returned to the station or factory for service and recalibration. A somewhat more troublesome problem with the rain gages is the tendency for the strip chart to expand and contract with changes in humidity. In some instances, charts have expanded more than 1/16 of an inch between service calls. These problems affect both time and precipitation amount. Pen drag on a slackened and moisturized chart may slightly lift the chart on the drum and may even stop the clock. Because of the dynamic and random nature of the problem, a quantitative estimate of the errors is not possible.

The third factor affecting the quality of the precipitation data is human error during servicing and data tabulation. The accuracy of manually setting the start of the data trace at the correct time on the strip chart is principally dependent on the resolution of the time gradations delineated on the chart. Accuracy increases with finer gradations. Data tabulation errors arise from misreadings of time or accumulation, faulty coding and human bias in interpolating data (time and volume) between gradations.

3.2 Runoff/Stream Flow

Runoff data are analyzed for total volume and the time distribution of runoff rates. The mechanical problems and human errors which affected the accuracy of data measured by recording rain gages also apply to determining runoff rates and volumes. With proper training and frequent field service checks, the impact of many of these errors on data quality can be minimized as already discussed.

Higher stages on the NAEW watersheds occur in response to high intensity, short duration storms. Flood peaks pass so rapidly that current meter transects cannot be completed for most events. Field calibration of every runoff measuring device is desirable but not achievable for the entire range of stages at the NAEW. Therefore, there has been no quantitative check on how well laboratory ratings fit the various devices. Profiles of weirs and flumes have been surveyed and rating corrections made for variations from design.

Furthermore, rating curves for standard drop-box weirs are incomplete in that they have not been established for high stages. NAEW drop-box weirs have experienced flows that reached beyond the rated range.

A significant source of error is how closely the approach to the measuring structure conforms to design specifications. The impact of noncompliance is clearly reflected in the data from the drop-box weir's high and low flow records for the station's study of surface mining impacts on watershed hydrology. Theoretically, the high flow recorder should activate once a unique stage is reached at the low-flow measurement point. An analysis of data from three surface-mined watersheds shows this not to be the case during the active mining and early reclamation periods. It is during these periods that heavy sediment loads are deposited in the approach to the weir after moderate to intense storms. Under these conditions, recorded high flow observations are labelled as estimated values.

The utilization of two instruments with different timing mechanisms and recording charts to measure high- and low-flow stream stages, highlights the difficulty of achieving absolute time synchronization. For dually instrumented station watersheds, times at which the upper threshold low flow stages are observed to occur can differ by more than 5-10 minutes from the times that high-flow recorders are activated. In these cases, breakpoint data on the higher resolution chart are used to establish the necessary corrections. Thus, although it is possible to construct a reasonable reproduc-

tion of runoff hydrographs, the time frame of the hydrograph relative to precipitation may differ somewhat from the actual. The overall accuracy is determined by the temporal resolution selected for the recording instrument.

The heavy volume of sediments lost from disturbed watersheds poses additional problems. In the case of the natural rainfall plots, the drop-box weir works well for small to moderate sized rains. Heavy rains can erode much sediment from a plot and plug the sediment trap of its weir. This invalidates the hydrograph for that event.

During heavy rains when large particles are washed off the plot, some can lodge in the V-notch section of the weir and cause spurious high stages. Sediment, if not manually removed from within the box after each runoff event, can accumulate and invalidate the rating. This is not a serious problem when servicing is frequent.

Gage zeroes can be off at the end of an event, sometimes for unknown reasons.

Freezing of the sediment traps, stilling wells, intakes, and of the V-notch section may occur if power failures shut off heaters.

3.3 Sediment Concentration

The analysis of sediment samples from station watersheds is limited to the determination of total sediment loss per storm. For surface-mined watersheds, discrete samples are taken during periods of storm runoff and analyzed for particle size distribution. Consequently, the procedures applied to the instrumentation required various levels of sophistication. The more complex analyses, obviously, pose the greatest problems.

At the NAEW's small watersheds, sediment loss is reported as the solid material that passes through the flume during each runoff event. After some events, sediment is shoveled from the approach floor that was transported from the watershed during the event but deposited on the flat concrete approach without carrying through the flume. The shoveled amount at various water contents is roughly measured or estimated, depending upon specific research objectives. Better, and possibly standardized methods, are needed for quantifying the volume of this material and for determining when the material was deposited and the impact on the stage-discharge relationship.

A similar problem exists at large watersheds. Each weir forms an upstream pool. The pool acts as a settling basin which must periodically be cleaned out to maintain calibration. Coarse eroded solids moving down stream during storms are deposited in the pool and do not pass through the weir. The material is backhoed out by the ton but no estimates of the amount nor the time of deposition have been documented. Therefore, sediment transport values accurately define transport through the weir, but do not account for the coarse material that is deposited in the pool above the weir. The measurement of sediment concentrations in runoff from surface-mined watersheds is extremely difficult. One of the foremost problems is the design of a suitable intake. At one such watershed, during the mining period when high sediment conditions were experienced, sediment would deposit under the intake. To assure that a similar problem did not occur at another surface-mined watershed, a movable intake was installed. However, during high flow where large rocks and logs are transported, the intake can be moved and held above the water level.

Measuring sediment loss from natural rainfall plots, designed to represent severely disturbed land, has been found to be a difficult procedure. The biggest problem in achieving good quality records for the plots is the accumulation of large

amounts of sediment during extreme events.

The times that samples are taken are marked directly on the runoff-chart. The intent is to correlate stream stage with sediment concentration, and also to verify that the number of samples taken agrees with the number indicated on the charts. On several occasions, the times of occurrence on the high and low flow charts differed by as much as 10 minutes.

An adequate pump to transfer sampled water from plots is a problem. Due to the low head loss in the gravity sampling system, pumps are required to pump water from the sump into 55-gallon drums in tandem. The sediment concentrates in the sump and eventually, during a large event, the sediment can submerge the pump intake. A peristaltic pump was tried on one plot with good results, but the cost of this type is prohibitive.

3.4 Chemical Concentration

With the equipment available at NAEW and the use of standard methods, the accuracy of the chemical concentration data is good to excellent for most analyses. Total nitrogen analyses tend to be less accurate than most other analyses because of currently available methodology. Nevertheless, they are still acceptable for meeting research objectives. Sample refrigeration at the collection site inhibits deterioration due to chemical activity.

The limits of error for the chemical concentrations are smaller than for the field hydrology data. Therefore, the accuracy of chemical transport data, the product of the chemical concentrations multiplied by the volume of flow, is dependent primarily upon the accuracy of the runoff data.

Table 2 contains a summary of our evaluation of the quality of data collected by the several instruments discussed.

Recommendations

(1) Develop field procedures to check the ratings of runoff measuring devices on watersheds subjected to short duration flooding and rapidly changing stages.

(2) Develop instrumentation and recording mechanisms to quantify the growth and migration of shoals in approaches to gaging structures.

(3) From laboratory studies, develop analytical procedures for determining the influence of observed upstream cross section changes upon broad crested and drop-box weir ratings.

(4) With laboratory modeling, complete the calibration of the drop-box weir at high stages.

(5) Design data acquisition systems with emphasis on electronic measurement and machine readable data storage. Utilize mechanical instruments only as backup to the primary system.

(6) Minimize or eliminate manual processing of field charts in order to reduce or exclude human bias from entering the record.

Table 2 Data Quality Evaluation

Description of current stations	Number of stations	Estimate of data quality	Special problems and comments
A. Precipitation			
Pit-gage	1	Good-rainfall	Blowing and drifting snow
		Poor-snowfall	
Standard recording gages	12	Good	Catch deficient with snow and wind
Dual recording gages	4	Good	Catch deficient with snow and wind, and actual amounts computed by ratio of shielded to unshielded catch
B. Runoff/Streamflow/ Groundwater			
Drop-box weirs (watersheds)	3	Good-stable watersheds	
		Poor-radically disturbed watersheds	Heavy sediment deposition in the approach and plugged intakes to stilling wells
Broad crested weirs	4 @ 2:1 1 @ 5:1	Excellent	Gradual sediment depositions in the approach
Parshall Flume (as backup to one of the broad crested weirs)	1	Good	(Applies to watershed in meadow) Heat enclosures required
Columbus deep notch	1	Good	Gradual sediment deposition in the approach
Groundwater-wells with recorders	1	Good-spring, summer, fall	Mechanical failure
		Fair-winter	Frosting of pulley and counterweighted float assembly
Groundwater-wells with tape measurement	1	Excellent	Monthly measurements
Drop-box weirs (Plots)	14	Excellent	Ice, sediment in traps during large events
C. Sedimentation			
Coshocton wheel samplers	12	Fair-excellent	Quality of data depends on use of sample splitter.

Table 2 Cont'd.

Description of current stations	Number of stations	Estimate of data quality	Special problems and comments
Coshocton vane samplers	6	Excellent	No-problems
Plot samplers	29	Unknown-data not processed	Sump fills up during extreme events
ISCO samplers	2 in tandem	Good-excellent	Infrequent battery failure, hole in tray too small for high sediment loads
Chickasha	1	Good-excellent	None
D. Water Quality			
Precipitation sampler (wet and dry)	1	Excellent	Contamination of collection due to mishandling, improper sealing, battery failures
Precipitation sampler (wet)	1	Excellent	Contamination of collector due to mishandling, battery failures, improper sealing
Grab samples	4	Good	Temporal representativeness
Raingages	5	Unknown	Prestorm aerial contamination

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ACQUISITION AND QUALITY OF WATERSHED DATA FROM THE SOUTHERN PLAINS WATERSHED AND WATER QUALITY LABORATORY

by

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INTRODUCTION

The mission of the Southern Plains Watershed and Water Quality Laboratory, headquartered at Durant, OK, is to develop information needed to protect and manage the quality of the nation's water resources arising from agricultural and non-urban lands. A more specific objective is to evaluate the quality and quantity of water from agricultural watersheds as practices and management systems evolve to meet increasing demands for food, fiber, water, and energy. The laboratory develops criteria and techniques for identifying and controlling agricultural non-point sources of pollution. The mission is achieved through research activities of a multidisciplinary staff organized into four Research Units: (1) Hydrology; (2) Erosion and Sedimentation; (3) Chemical Transformation and Transport; and (4) Aquatic Ecosystems. Watersheds at Chickasha, OK, and cooperating locations at El Reno and Woodward, OK, and Bushland and Temple-Riesel, TX, generate basic data and information for analysis, interpretation, and publication at the laboratory at Durant.

The present unit was organized in 1978, and represented a merger of the U.S. Agricultural Water Quality Management Laboratory, Durant, OK, and the Southern Plains Research Watershed, at Chickasha, OK. The Durant unit was established in 1969 to investigate the relationships between uses of agricultural chemicals and water quality. The Chickasha unit was established in 1961 in response to Senate Document 59, to evaluate the impact of the SCS flood control program on the main stem of a river.

DATA ACQUISITION PROGRAM

2.1 Precipitation: The raingage/precipitation research program at the Chickasha unit began in 1961. That spring, the first gages, equipped with recorders, were installed on a 1130 mi^2, central reach area of the Washita River Basin between Alex and Anadarko, on the main stem of the river. Installation of the basic 168 gage network was completed the following October. Since then, the network has operated continuously and generally remained intact. Within the area, some additional gages were added on smaller subwatersheds, with a maximum of 230 gages in operation in 1972.

Normal operating procedure for the network has been to change raingage charts weekly, or as soon as possible after large storms, in order to facilitate chart reading and processing. Pens and clocks are changed when malfunctions are noted, to assure accurate time recording and legibility of the chart trace. Calibration of the gages is continually monitored, by measuring rainfall catch with the standard tube/stick method. Quality of the data has been acceptable for normal and above-

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normal conditions, when compared to results from the Weather Bureau data collection program.

2.2 Runoff: Runoff data collection began in 1961. Record lengths range from two to 30 years (two watersheds had prior U.S. Geological Survey records) for 80 watersheds, with a mean record length of 8.1 years. The watersheds range in size from 1.48 acres for a gully research watershed to 4,787 mi^2 for the Washita River Basin upstream from Alex, OK.

Precalibrated H-flumes and triangular weirs have been used to measure runoff for 39 small watersheds. Santa Rita flumes are being used on four newly instrumented, highly erosive, small watersheds. Highway box culverts with weir sills, calibrated by modeling at the USDA-ARS Water Conservation Structures Laboratory, Stillwater, OK, have been used for two other small watersheds.

Large, broad-crested, concrete weirs, calibrated with current meter discharge measurements, were used for 10 medium-size watersheds. These weirs afford control at lower flow stages but diminish to channel control at bankful or out-of-bank stages. Higher flows require periodic current meter discharge measurements (night or day) to obtain the records.

Flow records for 12 large watersheds have been obtained by current meter gaging of natural channels. At 13 other varying size watersheds flow records have been obtained with ponds or reservoirs by monitoring the water stages, determining the stage-volume relations, and determining the stage-out-flow relation of the spillways. Reservoir stage data are reduced to inflow and outflow data with a program by Schoof (14).

Numerous practices have been employed through the years to assure runoff data quality. All gaging stations are routinely visited weekly to check the stage recorders (for correct time, gage height, chart supply, and clock stoppage), to clear sediment from the intakes or stilling wells, and to check the N gas supply and bubble rate (for those stations with a bubble gage). Current meter discharge measurements are usually made, especially for those stations with natural channel flow control.

During stormflow periods the stations are generally attended (night and day) and sufficient current meter discharge measurements are made (as prescribed by the research hydraulic engineer) to assure good quality data. During the early project years, classroom training sessions were held, instructional brochures were prepared (unpublished), and field practice sessions were held on making good discharge measurements. New employees were assigned to experienced workers until they were properly trained. U.S. Geological Survey Water Supply Paper 888 (7) was used extensively as a training aid.

In a study of flow velocities obtained with Ott and Price meters (R. R. Schoof, personal communication), the average velocity deviation was only 1.7 percent of the mean and the maximum deviation was 4.5 percent of the mean. Another study by Schoof (11) determined the variations in discharge measurements attributable to different operators and to the type of suspension, rod or cable. Schoof also determined the probable accuracy of monthly and annual flow data at two gaging stations by using 1/4, 1/2, 3/4, and all of the discharge measurements (13). Hunt et al. (8) invented an orifice device that lessens the loss of stage data when bubble gage orifices become inundated with sand.

All stage chart data are tabulated by hand, and checked to eliminate small errors found with a trial of electronic chart readers. These data are recorded

on magnetic tape and rechecked. An electronic computer processing program (12) contains additional error checks.

In association with the runoff studies, 750 holes were drilled to bedrock in the Washita River alluvium to determine the cross-sectional configuration of the major aquifer and to assess the magnitude of ground water flow in the reach. From 1961 to present, ground water levels have been obtained on 244 wells at monthly intervals using manual tape downs and water level recorders. Several equipment modifications and innovations have helped maintain data quality in the ground water research program. An electrical water level sensor that can be used in existing small diameter wells (1.5 to 2 in) permits data collection without having to drill costly 6-in diameter wells. Insects that would foul instruments are retarded with mothballs. PVC well casings that permit finer perforations are used to minimize clogging from "fines" entering the casing. Diesel oil layers are used to prevent freezing of wells with shallow water tables. Wells subject to sealing are flushed periodically, and brass water level sensor points are periodically polished.

2.3 Sediment Concentration: Sediment yield data have been collected at 70 of the 80 watersheds where runoff data are collected. At 58 watersheds sediment concentration data have been collected at intervals throughout flow events. Sediment yield computations could then be made with the continuous-concentration procedure, the most accurate of the several data processing procedures. For the lack of sufficient samples on three other watersheds, yields were determined partly or entirely with the less accurate flow duration-sediment transport curve procedure. For the 13 watersheds where runoff records have been determined with ponds or reservoirs, sediment yields have been determined with reservoir sedimentation surveys. At two of these reservoirs inflowing sediment has been measured with gaging stations. At three of the reservoirs the outflowing sediment has been measured.

Prior to about 1967 all suspended sediment samples were collected with manually-operated US DH-48, US DH-59, and US D-49 depth-integrating, suspended sediment samplers. After 1967, automatic pumping suspended sediment samplers were used at 54 of the gaging sites. Sampler models included the US PS-66, US PS-67 and the Chickasha Sampler (6).

Numerous practices have been employed to maintain sediment record accuracy. Classroom and field training sessions were held on how to take good equal-transit-rate (ETR) samples. Instructional brochures (unpublished) were prepared and specific sampling requirements were posted at each gaging site. All ETR samples were taken in duplicate to increase data reliability. ETR samples were taken frequently on most storm-flows (night and day) to define sediment concentration graphs. Base flows, if present, were sampled weekly.

Alternate methods of measuring sediment concentrations in streamflow were studied. The light attenuation method (1) was unsatisfactory, but the nuclear attenuation method (17) was very encouraging. The unmeasured (or unsampled) portion of the sediment load was studied to evaluate and improve unmeasured load estimates (2, 4, and 5). The SediGraph laboratory instrument, which has greatly speeded particle-size distribution analyses for silt and clay, was evaluated by Welch et al. (18) and Schiebe et al. (10). Except for low sediment concentrations, instrument performance was good.

2.4 Chemical Transport: Since the early 1970's, there has been cooperative effort between the Durant/Chickasha locations to investigate the loss of nutrients from various unit source watersheds. From an initial 11 watersheds in the Reddish Prairie land resource area of the Southern Plains the program has been expanded to 36 watersheds and now provides representation also for the Rolling Red Plains,

High Plains, and Blackland Prairies. Both dissolved and adsorbed chemicals in runoff are determined, using EPA procedures as the basic guide (15). Laboratory equipment for the analyses include micro-distillation apparatus, a Technicon Autoanalyzer, and an atomic absorption unit. Samples are refrigerated (0-4 °C) as soon as possible after an event and are usually analyzed within six weeks. Periodic checks are made for potential sample deterioration by sequential determinations after sampling. To date, deterioration has not been a problem.

Accuracy is maintained through routine inclusion of water quality nutrient standards obtained from EPA, occasional spiking of field samples with analytical grade reagents, and the "method of additions". In certain cases, analytical determinations are made using more than one procedure, and results are compared. To assure precision, all water quality analyses are conducted in duplicate. New analyses are performed whenever duplicates vary more than a few percent. Additional details on the variability and reliability of the water quality data are given in a recent publication (9).

DATA QUALITY PROBLEMS

3.1 Precipitation: No particular problems have been reported by the raingage/precipitation work group.

3.2 Runoff: Problems obtaining runoff records at this location are not as severe as at some other locations. Since winters are short and usually not unduly cold, measurement problems associated with freezing are rare. Also, since most channel slopes are mild and most runoff results from frontal rain systems or large thunder storms, storm runoff is less flashy than in desert or mountainous areas. These factors, plus the fairly dense and generally all-weather road system, allow streamgagers good access to measure stormflow on those watersheds larger than about 15 mi^2.

Measurement problems associated with high sediment loads do exist, however. Although cobbles, gravel, and coarse sand are fortunately missing from the sediment load, high concentrations of fine sand, very fine sand, and coarse silt create problems. Sediment drops out of the flow immediately upstream from precalibrated weirs, thus shifting their rating and requiring periodic cleanouts. Sediment deposits in intakes and stilling wells during large flow events, and thus requires extra inspection during flow recessions and occasional cleanouts.

On larger alluvial sand bed channels with no flow measurement structure changing bed elevations (0.5 ft is common on some streams), and sand bar changes require frequent current meter discharge measurements to define shifts in the rating curve. At those locations where stage records are obtained with bubble gages, orifices inundated by sand result in lost stage records until a streamgager visits the station and changes to a higher orifice.

Trashy stormflow creates another type of measurement problem for Southern Plains streams. Since streams are generally lined with trees, the gradual downvalley meander migration erodes trees into the flow. These trees, dead tree trunks and limbs, grass and grass roots, and other dumped trash greatly hamper making accurate discharge measurements. Streamgagers must diligently watch the approaching flow and quickly crank the meter and weight clear of the water for any debris that might hang on the equipment and damage the meter. When small trash accumulates on the cable, the streamgager usually must crank the equipment all the way in to remove the trash. Since a trash-laden cable drags the meter and weight downstream, the cable is no longer vertical; thus complicating stream depth determinations. Fine roots in the flow wrap around the velocity meter

spindle and slow its turning rate. Consequently, with present available equipment, trash in the flow makes field work more strenuous, increases the required time to perform field work, and decreases the accuracy of measurements.

3.3 Sediment Concentration: Virtually all suspended sediment sampling problems result because the concentration of sand, and coarse silt under some flow conditions, is poorly distributed in the flow cross-section, especially with depth. For small watersheds where most samples must be collected with a pumping sampler and from a fixed point in the flow, it is suspected that sample concentrations are too low in the initial part of the hydrograph when the fixed intake is near the water surface. Later, near the hydrograph peak, sample concentrations probably are far too high because the same intake is then near the bottom of the flow. This problem is suspected to be most severe where Santa Rita flumes are used. Conventionally, sediment sampler intakes are located in one wall near the flume trough.

On the larger streams the same intake location problem exists. Efforts to use moveable intakes that would raise the intake point as the stream water level rose, were successful at one location but unsuccessful at two others.

Another problem is the US D-49 suspended sediment sampler that is used for taking ETR samples at higher flows. This sampler is not streamlined enough for higher flows at most streams. The sampler is swept too far downstream as it is cranked to the bed, and upon cranking reversal, it presumably oftentimes "plows" its nozzle into the bed. In a study of ETR measurements, Allen and Petersen (3) concluded that about 10 and 15 percent of all ETR measurements by experienced and less experienced technicians, respectively, were in error by 10 percent or more.

3.4 Chemical Transport: A particular problem has been obtaining a representative total sample (water plus sediment) for chemical analysis in runoff containing coarse sediment particles.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

1. Determine concentration accuracy of samples pumped from conventional intake points in H-flumes, above weirs, and in Santa Rita flumes. If accuracy is inadequate, then devise other intakes, fixed or moveable, or ways to improve sampling conditions by increasing turbulence hydraulically, mechanically, or pneumatically.

2. For larger streams develop a pumping sampler intake whose depth would vary as a ratio of total stream depth.

3. Improve the US D-49 sampler. It needs to be more streamlined to decrease drag. Investigate a nozzle system that would open only on the downward leg of depth integration. A "foot" piece on the bottom of the sampler could be used to close the nozzle upon striking the bed. One-way integration would eliminate the nozzle "plowing" problem, would result in fewer sample bottles per measurement, and would permit slower cranking speeds at high flow rates.

4. Develop an instrument that would measure flow velocities continuously at a gaging site. Preferably, the instrument would integrate velocities across the entire flow width and operate on some remote sensing principle, such as doppler sonar, so that the instrumentation would be on the sides of the flow rather than in the flow.

5. Modify the bubble gage orifice device of Hunt et al. (8) to reduce the frequency of removing sand from the reservoir and to maintain true water elevations inside.

6. Develop a more accurate clock drive (possibly electronic) for Leopold and Stevens A-35 stage recorders.

7. Streamline (and possibly integrate) the velocity meter and sounding weight arrangement to discourage trash accumulation and to encourage trash shedding when the unit is pulled from the water.

8. Develop data logging methodology to reduce or eliminate manual processing of data.

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REPORT ON QUALITY OF WATERSHED DATA FROM THE WATER CONSERVATION STRUCTURES LABORATORY
Stillwater, Oklahoma

by

Wendell R. Gwinn

INTRODUCTION

Precipitation and runoff data were needed for the design of soil and water conservation works in grassland areas of the Reddish Prairies of Oklahoma, Texas, and Kansas. This also provided an opportunity for research on the development of an inexpensive runoff measuring device that utilized existing highway culverts. Three watersheds, adjacent to and draining toward a highway, located twelve miles north of Stillwater were selected. Namely:

Watershed 37001	(W-1)	16.7 acres	3- by 3-ft wide culvert
Watershed 37002	(W-3)	92.0 acres	4- by 8-ft wide culvert
Watershed 37003	(W-4)	206.0 acres	twin 4- by 8-ft wide culvert

Ree and Crow (1954a,b) installed Villemonte weir sills in the culverts for low flow measurements. Water level and precipitation recorders were installed in June 1951 and operated continuously until January 1, 1973.

DATA ACQUISITION PROGRAM

2.1 Precipitation: Two weighing-type raingages were installed in June 1951 near the edge of W-3 and W-4. Two additional raingages were installed in July 1964: one at the center of gravity of W-1 and one at the center of gravity of W-4. These gages were added to give better rainfall measurement coverage for W-4 and to use the soil-moisture measurements on W-1. Timing errors were kept to a minimum using a standard clock as reference for all gages. Accuracy was approximately 1 minute.

2.2 Runoff: One of the main objectives of the study was to evaluate the performance of highway culverts equipped with Villemonte weir sills as flow measuring devices. Some difficulty was experienced with the culvert on the 206-acre watershed, W-4. This is a double-barrel structure with a weir sill in each. During periods of low flow, the water may not be divided evenly between the two barrels because of silt deposits on the culvert apron blocking the flow to one culvert. Thus the indicated discharge was twice the actual flow at times. The runoff values were corrected for ponding upstream of the culverts and in farm ponds as reported by Crow and Ree (1964).

FW-1 water level recorders were used to obtain a continuous record of depth of flow at the culvert entrances. New 24-inch C.M.P. gage wells and recorder houses were installed in 1960 using interim standards later published by Holtan et al. (1962). Sediment will accumulate under the float and produce false recession hydrographs. Alertness on the part of the observer and occasional shovel work has kept the difficulty at a minimum.

The relationship between precipitation and runoff for the three watersheds using the USDAHL model was reported by Crow et al. (1977, 1980) and Ree et al. (1977).

2.3 Sediment Concentration: An automatic pumping Chickasha sediment sampling installation was completed in May 1969 for W-1. The measurements were continuous until January 1, 1973, except for periods when the pump malfunctioned.

2.4 Chemical Concentrations: These watersheds were not instrumented for measuring chemical concentrations.

DATA QUALITY PROBLEMS

3.1 Precipitation: Good quality data depends on the alertness, care, and training of the observer, as well as on the device or instrument being used. In the initial years of the project (1951-55), students were used as observers. A full-time technician was used from 1956 to 1972, and data handling for this period was very good. However, the records were still subject to errors due to wind, snow, and convective thunderstorms.

3.2 Runoff: Shifting of the gage zero between the gage well and the measuring device was a problem with poor gage wells from 1951 through 1959. Silt below the float and on the culvert entrance required alertness on the part of the observer. The weir sills were placed inside the culvert downstream of the entrance to retain the maximum capacity of the structure. Because of the slope of the barrel and the gage well location upstream of the entrance, the low flow head control measured by the gage well shifted from the weir to the wide culvert entrance. Therefore, this type of flow measurement should not be used where long periods of low or base flows are expected.

3.3 Sediment Concentration: Pump malfunction was the major source of operational error. In some years, 30 percent of the events were missed due to failure of the pump to prime. Other problems were associated with selection of an appropriate sampling point. There is need for information on adjusting point samples to total suspended sediment.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

Watershed W-4 was closed in January 1973. The Agricultural Engineering Department of Oklahoma State University has operated W-1 and W-3 since April 1973. No instrumentation development projects are needed for the Stillwater location.

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DISCHARGE RATINGS OF A SANTA RITA FLUME

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by

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INTRODUCTION

A Santa Rita type flume is being used to measure runoff and sediment from roadside erosion in the Little Washita watershed near Chickasha, Oklahoma. The details of this flume are presented in Figure 1. The Erosional Processes Research Unit of the Southern Plains Watershed and Water Quality Laboratory, Durant, Oklahoma, requested full-scale tests to determine discharge characteristics of the flume. The sheet metal flume was constructed in the Chickasha shops and installed in a field channel at the Stillwater laboratory. Tests were run to determine the discharge characteristics of the flume.

FLOW MEASUREMENT

The flume was evaluated using a sharp-edge 90° V-notch weir as a standard for flow measurement. For head $H < 0.2$ ft, the equation for a V-notch weir

$$Q = (0.638 + 0.0512 \log_{10} H)(8/15)(2g)^{0.5}(\tan \theta/2)(H)^{2.5} \quad (1)$$

was developed from data by Barr (1910) where Q = discharge in ft^3/s, H = head in ft ($H<0.2$), g = acceleration due to gravity in ft/s^2, and θ = total angle of V-notch. For $H \geqslant 0.2$, the equation

$$Q = (2.395 + N/H^e)(\tan \theta/2)(H)^{2.5} \quad (2)$$

developed by Lenz (1943) was used, where N = 0.068, 0.087, 0.102 for θ = 90°, 60°, 45°, respectively; e = 0.588, 0.582, 0.579 for θ = 90°, 60°, 45°, respectively, water temperature = 70°F, and $N/H^e = <0.009$. The above constants expressed in equation form are

$$N = 0.0679/(\mathrm{Tan}\ \theta/2)^{0.459} \quad (3)$$

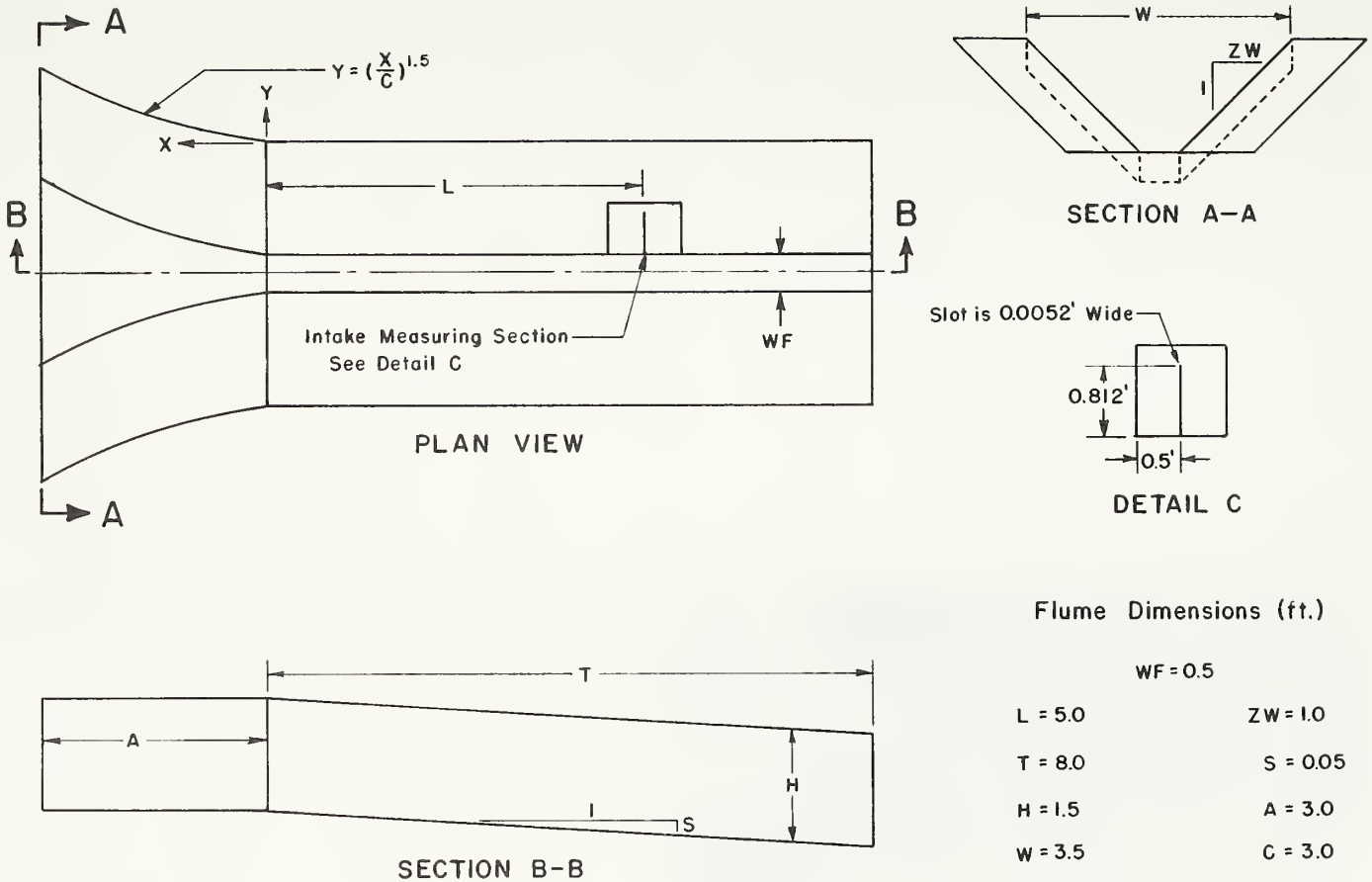
and $$e = 0.588(\mathrm{Tan}\ \theta/2)^{0.0176} \quad (4)$$

The brass weir was mounted at the end of a 4- by 8-ft stilling box located downstream of the flume as shown in Figure 2. The maximum capacity of the stilling box was 3.5 ft^3/s.

An ogee weir at the entrance to the supply canal was used to measure the flows above 3.5 ft^3/s. Losses between the ogee weir and flume were determined by using the difference in discharge between the ogee and V-notch weirs for steady flow conditions. These differences were calibrated with head in the flume for each set of data.

DISCHARGE RATINGS

Computed: A rating table using the nominal dimension shown in Figure 1 was computed by Dr. Roger E. Smith using a program reported by Smith et al. (1982). The following coefficients were used in the program:



Flume Dimensions (ft.)

WF = 0.5	
L = 5.0	ZW = 1.0
T = 8.0	S = 0.05
H = 1.5	A = 3.0
W = 3.5	C = 3.0

Figure 1.--Santa Rita Flume used in measuring runoff and sediment from roadside erosion in Little Washita Watershed near Chickasha, Oklahoma.

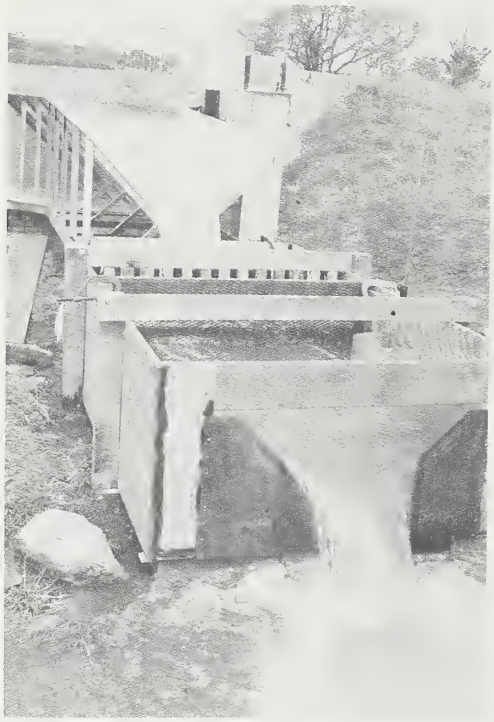


Figure 2.--90° V-notch weir and stilling box used to measure flow through the Santa Rita flume. (Unrestricted flat approach, Q=1.61 ft^3/s, V-notch H=0.84 ft, Flume H=0.36 ft)

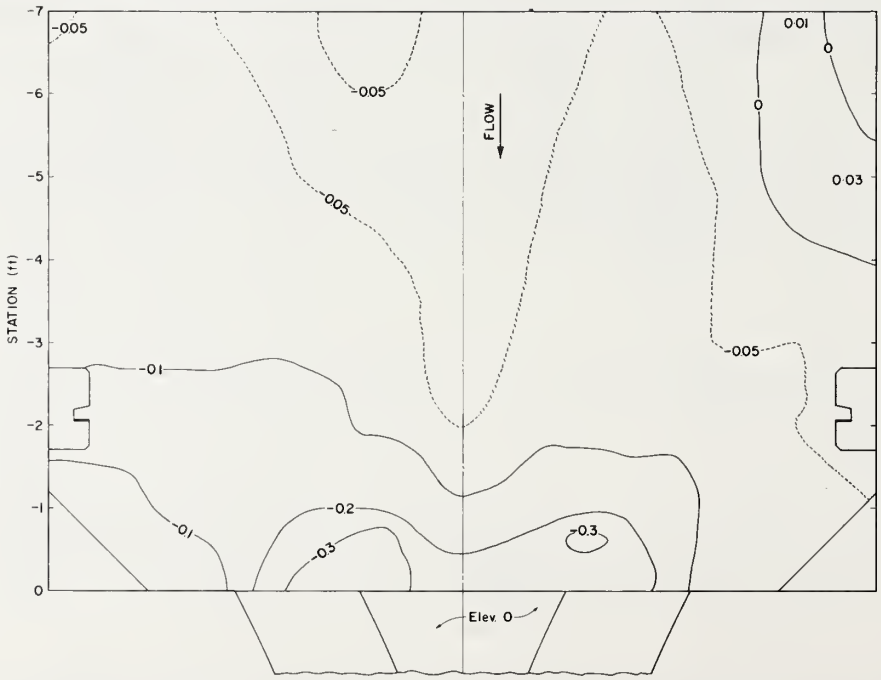


Figure 3.--Entrance contours after the unrestricted flat approach rating.

energy coefficient alpha = 1.1

Chezy C roughness = 90

eddy loss ratio = 0.05

roughness hydraulic exponent = 0.5

The flume was installed in the test channel, and the average dimensions of the flume are given in the following table:

Distance from Control Section X	Slope of Flume Sidewall ZW	Width of Floor Section WF
0.0, 0.5, 1.5, 2.0	0.997 + 0.00605X	0.508 + 0.003X
2.5, 3.0, 3.5	1.0 + 0.00465X	0.535 - 0.0105X
4.0, 4.5, 5.0	0.962 + 0.0141X	0.621 - 0.032X

The slope S was 0.0479. These dimensions, along with the above coefficients and program by Smith et al. (1982), were used to compute the adjusted rating and will be referred to as the computed rating Q_c.

Unrestricted Flat Approach: A fine-textured sand (blow sand) was used to fill the approach to form a flat bed level with the floor of the entrance to the flume. During the tests some of the sand was eroded by the flow. The contours (ft) after the rating are shown in Figure 3.

The rating did not agree with the computed rating except at two points. Manning n was used as a tool to show the difference between the ratings. Manning's equation was used in the analysis:

$$n = 1.486\ R^{2/3}\ S^{1/2}\ A/Q \qquad (5)$$

where R = hydraulic radius, computed using head in gage well with flume dimensions (ft); S = slope of flume floor (0.0479); A = area, computed using head in gage well with flume dimensions (ft^2); and Q = discharge (ft^3/s).

The results of the unrestricted flat approach rating are shown in Figure 4 as circles. Also, the discharge ratios between computed Q_c and unrestricted flat approach Q are shown in Figure 5 as circles. The largest deviation from the computed occurred for $H < 0.09$ ft (R = 0.07). The flow is approximating a condition dominated by viscosity with deviations inverse to head. The minimum ratio of Q_c/Q was 0.897 (H = 0.229 ft, R = 0.145 ft), and the maximum ratio of Q_c/Q for $H > 0.09$ ft was 1.036 (H = 0.845 ft, R = 0.389 ft).

Narrow Steep Approach With No Sediment: The approach to the flume was made using plywood to form a shape shown in Figure 6. The channel had 2-ft bottom width, 1 to 1 side walls, and a slope of 0.05 in the downstream direction, with the bottom 0.5 ft below the floor of the entrance.

The rating for the narrow steep approach (squares in Figures 4 and 5) was similar to the unrestricted flat approach, but the deviations from the computed rating were slightly larger. The largest deviations from the computed occurred for $H < 0.1$ ft (R = 0.074). The flow in this range is dominated by a boundary layer with deviations inverse to head. The minimum ratio of Q_c/Q was 0.887 (H = 0.284 ft, R = 0.168 ft), and the maximum ratio of Q_c/Q for $H > 0.1$ ft was 1.055 (H = 0.657 ft, R = 0.319 ft).

Narrow Steep Approach With Fixed Bed: The laboratory is not equipped to feed and measure large amounts of sediment over a prolonged period of time. A sediment bed was

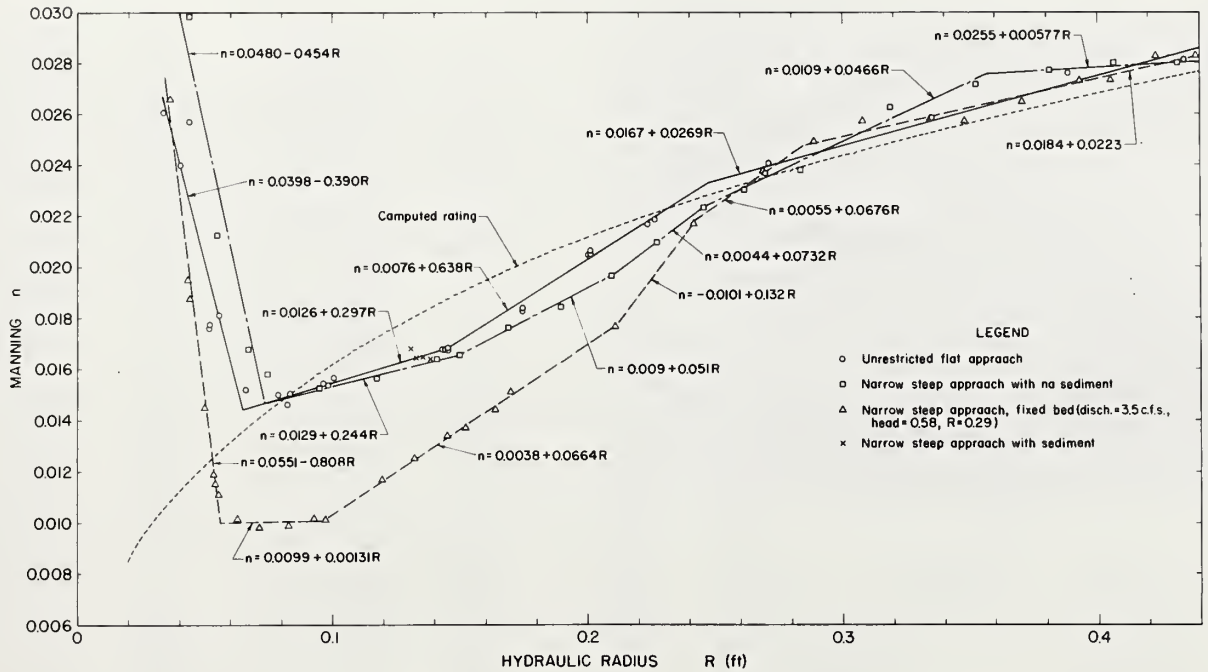


Figure 4.--Computed roughness coefficient using the head measured in the gage well of the flume.

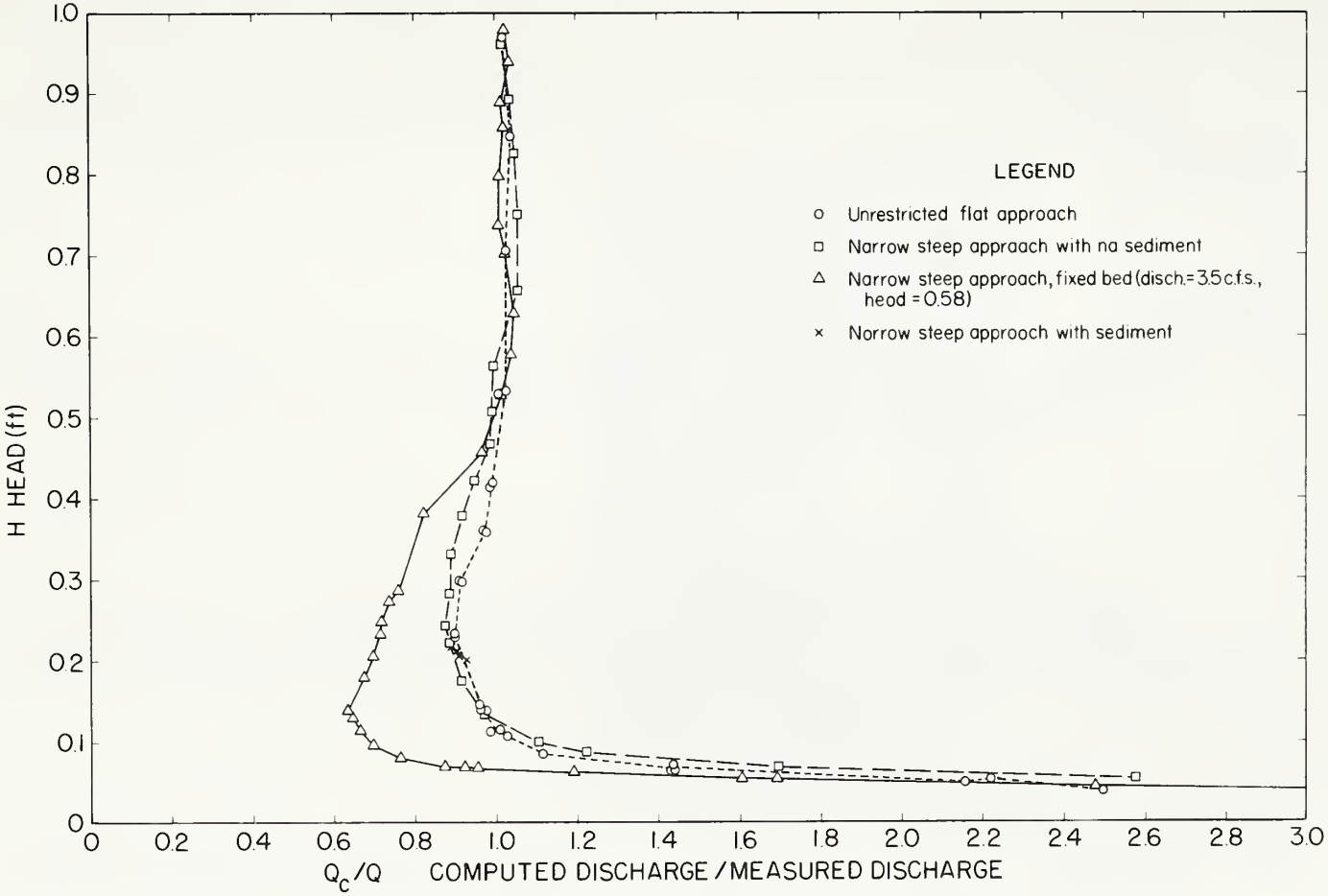


Figure 5.--Discharge comparisons for Santa Rita flume ratings.

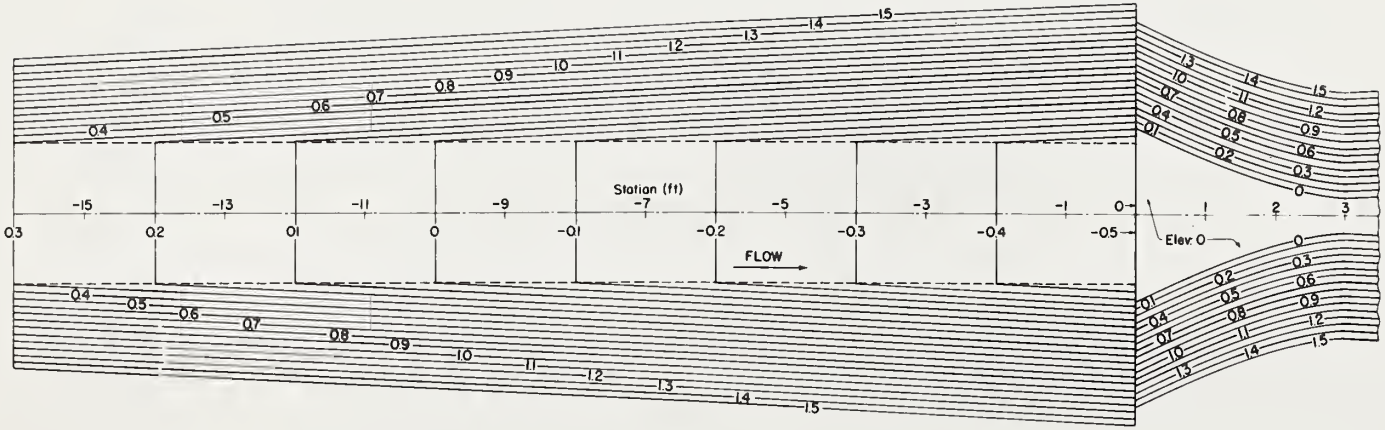


Figure 6.--Contours of a narrow steep approach to a Santa Rita flume.

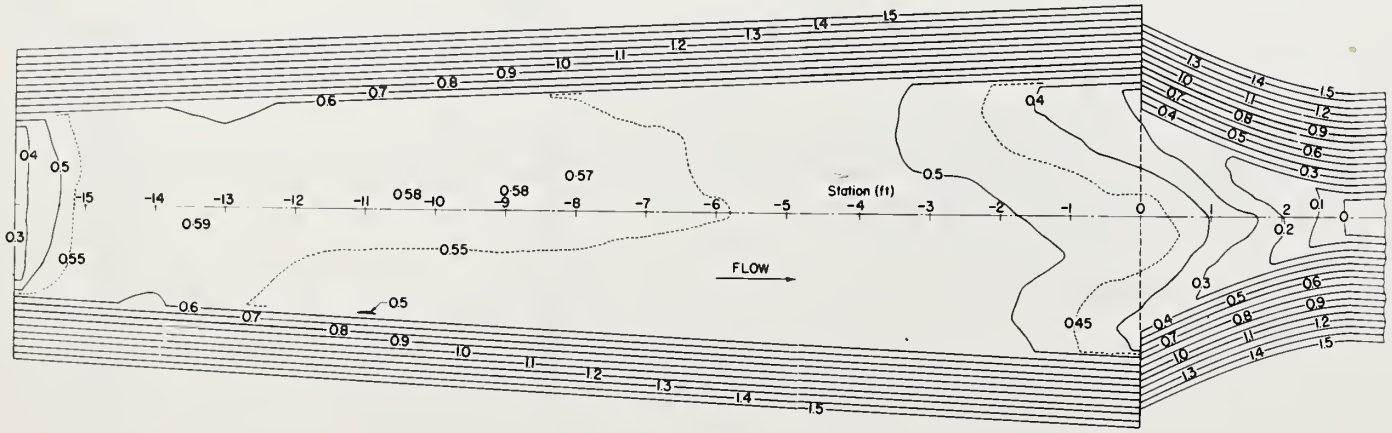


Figure 7.--Entrance contours of the narrow steep approach with fixed bed (bed formed with discharge = 3.5 ft^3/s and head = 0.58 ft).

formed using a washed sand with diameters of 595, 415, and 290 microns for the 84, 50, and 16 percent passing, respectively. The discharge used was 3.5 ft^3/s with H = 0.58 ft and R = 0.29 ft. The bed shape is shown in Figure 7. The bed was fixed using compacted sand-cement mixture to form a concrete surface molded to the original sand bed elevations (ft).

The resulting clear water rating with the fixed bed is shown as triangles in Figures 4 and 5. The minimum ratio of Q_c/Q was 0.634 (H = 0.137 ft, R = 0.097 ft). This increase in discharge over the computed discharge is caused by the acceleration of the flow and unsymmetrical wave formation as shown in Figure 8. For $H > 0.064$ ft, the maximum ratio of Q_c/Q was 1.047. for $H < 0.064$, the maximum measured Q_c/Q was 6.98 (H = 0.024).

Figure 8.--Unsymmetrical wave formation reduces the depth of flow in the gage well (discharge = 0.566 ft^3/s, head = 0.137 ft).

Narrow Steep Approach With Sediment: A washed sand with diameters of 595, 415, and 290 microns for the 84, 50, and 16 percent passing, respectively, was fed approximately 15 ft upstream of the flume entrance using a hand shovel. The material was spread evenly across the entrance at a rate that would not produce a buildup under the point of feeding. The clear water discharge before the start of feeding was 1.0 ft^3/s. The filling of the approach channel required 38 minutes of steady feeding. Flow measurements with sediment were made over a 15-minute period between 45 and 60 minutes from start of feeding. The flow through the flume ranged from 0.81 ft^3/s at the beginning down to 0.67 ft^3/s at the end of the 15 minutes. The reduction in discharge was due to the sediment buildup in the flume entrance. At the end of 60 minutes, the flow upstream was shut off instantly using a by-pass gate. The resulting sediment contours (ft) are shown in Figure 9.

The results are shown as data points labeled X on Figures 4 and 5. The rating with the sediment was almost the same as with no sediment. The ratio Q_c/Q varied between 0.89 and 0.93 for this limited flow range.

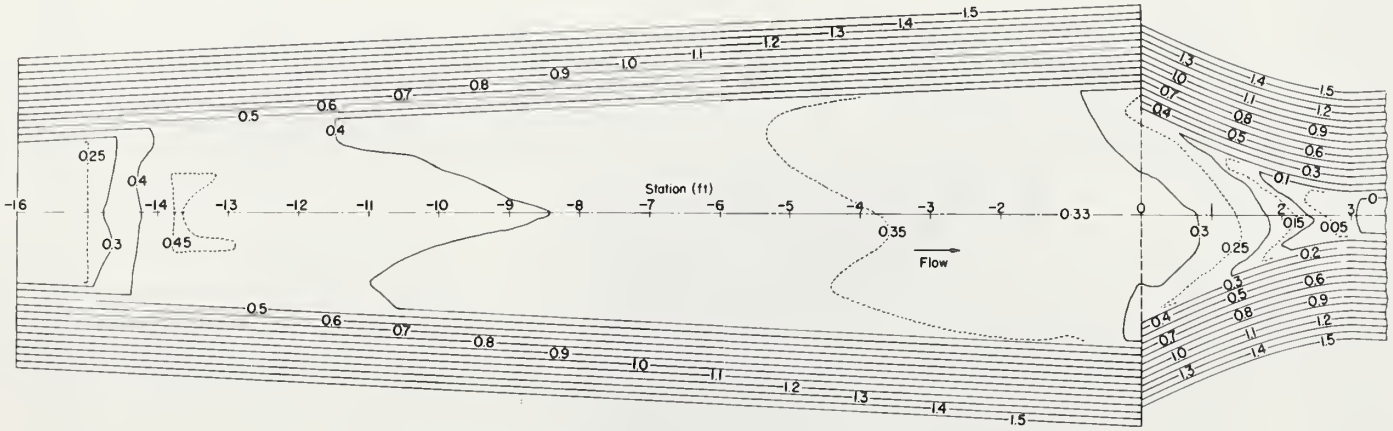


Figure 9.--Entrance contours of the narrow steep approach after 60 minutes with an average discharge of 0.72 ft^3/s.

SUMMARY

The computed rating can be used for heads greater than 0.4 ft with expected errors of approximately 5 percent depending on the coefficients chosen. For heads less than 0.4 ft, the flume should be field-rated for sites where large size sediment is expected. The computed rating should not be used for $H < 0.1$ ft.

Three events from the roadside watershed (area 7.83 acres) with accumulated runoffs of 0.852, 0.241, and 0.0452 inches were recomputed using correction factors estimated from Figure 5 for unrestricted flat approach. The corrected values were 0.786, 0.230, and 0.0312 inches, respectively. The mathematical computed rating over predicted by 7.7, 4.6, and 31 percent, respectively. The measurement of small events involves large errors as might be expected.

A maximum discharge of 33.4 ft^3/s for $H = 1.5$ ft was listed in the rating table. However, the flume overtopped at the entrance for a head of approximately 1 ft with a maximum discharge of 10 ft^3/s. For flows above 1 ft, the indicated head would give discharge values too low due to overtopping. Sampling of sediment from the flume is a problem that needs further study.

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REPORT ON QUALITY OF PRECIPITATION, RUNOFF AND EROSION PLOT DATA FROM THE COLUMBIA PLATEAU CONSERVATION RESEARCH CENTER

by

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INTRODUCTION

The mission of the Center is to carry out research for developing better practices, techniques, and equipment for crop production and soil and water conservation in the Columbia River Plateau and related land resource areas. One aspect of this broad research program is the conservation and optimum use of precipitation, soils, and runoff water with a specific objective of developing practices to maximize infiltration and retention of precipitation and to minimize runoff and soil loss.

The Pacific Northwest dryland grain region comprises about eight million acres of cropland in Idaho, Oregon and Washington. Climate, topography, soils and tillage practices can combine to produce a serious water erosion hazard. Estimated average annual soil losses range from 2 to 25 tons per acre and individual field losses as great as 100 tons per acre have been reported. In 1976 the Universal Soil Loss Equation was adapted for use in the Pacific Northwest for estimating annual soil loss (Wischmeier and Smith, 1978; McCool, et al., 1976). Since that time the various factors in the Universal Soil Loss Equation have been revised and adapted to conform to the Northwest conditions. Despite this considerable effort, there still remains a great deal of concern about the reliability of the equation for predicting erosion rates in the Pacific Northwest.

At a recent workshop meeting in Spokane (20 Feb 1980) two major goals were identified by ARS, SCS and university personnel. These were: 1) a medium range goal of improving the USLE in time for use both in the SCS 1985 National Erosion Inventory and conservation planning; and 2) development of a predictive soil loss equation or model specific to the states of Idaho, Oregon and Washington.

In order to achieve these goals and objectives we install, each fall, fully instrumented sites to gather the required data (Zuzel, et al., 1980). The sites are located over a wide geographical area encompassing 5 counties in northeastern Oregon. For the most part the plots are installed in planted winter wheat after summer fallow, a common tillage practice, although some plots are located in over-winter wheat stubble for comparative purposes. Whenever possible we utilize fields on which the farmer has done the tillage, planting and related operations. Each plot is designed to collect into holding tanks, all of the runoff and erosional materials produced from each 60 x 10 foot plot. The holding tanks are instrumented with continuously recording water level sensors which produce a cumulative inflow hydrograph. Each site is also equipped to continuously record soil temperature, air temperature, relative humidity and precipitation. Frost depth is determined weekly with 2 frost tubes. Snow depth and snow water equivalent is measured each week using a federal snow sampler. When a runoff event occurs, water and sediment samples are collected from the holding tanks and analyzed for soil concentrations and fertilizer type chemical concentrations.

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We also have a permanent erosion site consisting of 6 plots (13.3' x 110') near the Center. Instrumentation is similar to the remote sites. The design criteria suggested by Mutchler (1963) with some modification, were used to design and construct the collection and measurement systems.

DATA ACQUISITION SYSTEMS

2.1 Precipitation: Originally, all sites but the permanent erosion site were equipped with propane heated tipping bucket raingages. Due to problems involving large catch deficiencies, these gages were replaced with weighing type recording raingages. The weighing-type raingages are, however, subject to an accumulation of ice in the buckets and evaporation from the buckets. Snow water equivalent is sampled weekly using a federal snow sampler.

2.2 Runoff/Streamflow/Groundwater: All stations are equipped with total sediment and runoff collection tanks. A cumulative inflow hydrograph is obtained by installing a recorder and float in the holding tanks. In addition, each plot at the permanent site was equipped with a 60° V-notch trapezoidal flume and flowmeter. Problems associated with the flumes were sediment deposition in the flume and stilling well resulting in inaccurate flow volumes and rates.

2.3 Sedimentation: At all sites samples are obtained by hand sampling (from the holding tanks) after the event. A problem which can occur is inadequate mixing prior to hand sampling resulting in questionable determinations of total sediment. At plots where attempts were made to sample suspended sediment during the event, accuracy of the results are poor. Flow proportional sampling at these sites is impractical due to sediment accumulation in the stilling wells. Sampling during low flow events appears to be inaccurate in either the flow proportional or timed mode. A main reason for this is deposition of sediment at the sampling point.

2.4 Water Quality: Problems involved in determination of fertilizer-type chemical concentrations are similar to the problems involved with suspended sediment sampling. Generally, sub-samples obtained from the holding tanks provide reasonable estimates of actual fertilizer-type chemical concentrations. Table 1 summarizes the data acquisition systems presented in this section.

DATA QUALITY EVALUATION

3.1 Precipitation: Catch deficiencies associated with the propane heated, tipping bucket raingages were detected immediately by comparing gage catches with nearby National Weather Service data. Data quality is poor due mainly to the catch deficiencies probably associated with wind, sublimation at the collector and convective uplift at the collector. Currently, the characteristics of these gages are being evaluated at the Northwest Watershed Research Center in Boise, Idaho. Data from this cooperative study will provide a means of evaluating the performance of these systems. Meanwhile, weighing type recording raingages have replaced the heated gage at all sites. Data quality from these gages is good despite occasional recorder malfunctions. Problems still exist from catch deficiency with snow and wind. Sampling of snow water equivalent in areas of a transient and discontinuous snow pack presents unique problems. Sample points must be chosen for representativeness, estimates of snow cover must be made and sampling must be done frequently due to the transient nature of the pack. The combination of these measures can ensure at least fair estimates of snow water equivalent over small areas. In addition to being labor intensive, this method requires the use of well trained observers. Present technology does not provide an acceptable alternative for estimating snow water equivalent under these conditions.

3.2 Runoff/Streamflow/Groundwater: Since we use large holding tanks, estimates of total runoff are excellent, as are estimates of hourly runoff derived from the recorder record. Runoff rates for time increments less than 1 hour are not calculated because of the recorder time scales in use. It is not feasible to use an additional recorder with a finer time scale with currently available funding. The use of the 60° V-notch trapesoidal flumes in conjunction with flowmeters was discontinued. The data obtained with this system is poor to unusable due to sediment deposition in the flume approach and stilling wells.

3.3 Sedimentation: In general, determinations of total sediment obtained from sampling the holding tanks are considered very good. Correlation of replicate samples from the same tank was improved by using a high pressure, portable sludge pump to ensure proper mixing prior to sampling. Flow propotional samples taken during the event using a flow meter paced pumping sampler are poor to unusable for the reasons given in Section 3.2.

3.4 Water Quality: Samples obtained from the holding tanks provide good estimates of fertilizer-type chemical concentrations for the event provided that the analyses conform to standard methods and procedures. Concentrations during the event are not sampled. Estimates of data quality for systems discussed in this section are presented in Table 2.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

1. The technology to measure liquid or solid precipitation in areas of low intensity-long duration events is presently available (Rechard and Larson 1971; Hamon 1973; Rechard et al. 1974). The principal constraint is the cost of installing dual gages or a Wyoming shielded gage at each site.

2. Improved methods and instrumentation are needed for determining snow water equivalent of transient and discontinuous snowpacks. Photogrammetric and other remote sensing methods need to be explored and tested against on-site ground truth measurements.

3. With respect to verification of field sized runoff and erosion models, instrumentation and methods capable of accurately measuring runoff rates and instantaneous sediment concentrations is urgently needed. Adaptation of presently available equipment, designed for higher flow rates and lower sediment concentrations, does not seem to be a viable alternative.

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Table 1. Data Acquisition Systems

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Heated rain and snow gages	Deficient catch due to evaposublimation during snowfall	Replaced with weighing type recording raingages
Recording rain gages	Evaporation and ice	Antifreeze and oil used in gages
Snow water equivalent measurement	Transient and discontinuous snowpack	More frequent sampling; sample points chosen for representativeness; estimates of percent cover, photographs
2.2 Runoff/Streamflow/Groundwater:		
60° V-notch trapezoidal flume and flowmeter (total sediment and runoff collection tanks)	Sediment deposition in flume approach and stilling well	Cumulative hydrograph obtained by installing recorder float in holding tanks. Flumes removed
Recorder and float in holding tank	No data on first 2-3 inches collected in tank	None
2.3 Sedimentation:		
Total sediment sampling from holding tanks	Questionable results from hand mixing prior to sampling after large events	High pressure sludge pump used to ensure adequate mixing
Suspended sediment sampling during event	Flow proportional sampling not accurate due to sediment accumulation in stilling well	Changed sampling to a timed sequence after the start of the event
	Low flow sampling inaccurate in either flow proportional or timed mode	No solution to this problem with present equipment and configuration. Data used as index only
2.4 Water Quality:		
Fertilizer-type chemical concentrations	Inherent variability of analysis methods	Conform to standard procedures

Table 2. Data Quality Evaluation

Description of stations	Number of stations	Estimate of data quality	Special problems and comments
3.1 Precipitation:			
Heated rain and snow gage	None	-5% to -10% rainfall -10% to -30% snowfall	Catch deficiency due to evaposublimation during snowfall. Also some wind effect
Recording rain gages	Variable; 6 to 8 October through April	-10% to -15% for all conditions	Generally, gages are not located in high wind areas, but still some catch deficiency due to wind
Snow water equivalent measurement	Variable; 6 to 8 November through February	± 20%	Snowpack transient and discontinuous. Difficult to choose representative sample points and/or estimate percent of cover
3.2 Runoff/Streamflow/Groundwater:			
60° V-notch trapezoidal flume and flowmeter	None	± 40%	Inaccurate at low flows due to sediment deposition in stilling well and flume approach
Total runoff	Variable; 6 to 8 October through April	± 5%	None
3.3 Sedimentation:			
Flow meter paced pumping sampler	None	± 40%	Sediment deposition in stilling well and flume approach; low flow deposition at sampling point
Total sediment	Variable; 6 to 8 October through April	± 5%	Occasional problem due to insufficient mixing
3.4 Water Quality:			
Fertilizer type chemical concentrations	Variable; 6 to 8 October through April	± 10%	Occasional problem from insufficient mixing prior to sampling or insufficient mixing prior to taking subsample

QUALITY OF WATERSHED DATA FROM THE NORTHEAST WATERSHED RESEARCH CENTER

W. J. Gburek and R. N. Weaver

INTRODUCTION

The Northeast Watershed Research Center (NWRC), created in 1966, has its main offices at University Park, Pennsylvania. The Center is chartered to conduct research on the hydrology and associated chemical and sediment transport resulting from land use and management inherent to the northeastern United States. Research is directed toward larger-scale land units, such as farm- or watershed-sized areas, that are under agricultural use, potentially convertible to agricultural use, or being converted from agriculture to another land use.

The NWRC conducts the majority of its field research within the East Mahantango Creek Watershed, a 162-sq-mi area tributary to the Susquehanna River approximately 30 mi north of Harrisburg, Pa. The watershed is within the Northern Appalachian Ridge and Valley Physiographic Province, and is typical of larger rural watersheds of the mid-Atlantic Region. Land use is approximately 70% agriculture and 30% forest; urban areas on the watershed are small and include only villages. Major farming activities are dairy, poultry, and livestock raising, carried out primarily on the valley bottoms, and the typical farm unit is less than 200 ac. The objective of most cropping is to provide forage and feed for on-farm consumption by livestock. Generally, the farmers follow good soil and water conservation practices, and there is little apparent evidence of erosion, stream eutrophication, or poor land and water management. The watershed and the NWRC research program have been fully described by Pionke and Weaver (1977).

The Mahantango Watershed is typical of much of the lower Northeast in climate, having warm, humid summers and cold, moderately long winters with foggy, cloudy, and damp weather and intermittent, moderate snow accumulation. Many winters it does not have continuous snow cover. Average summer temperature is approximately 70°F, while average temperature for the winter months is just below freezing. Fall through spring precipitation is primarily the result of large-scale cyclonic activity and frontal overrunning, while summer rainfall may be the result of the same conditions, or more commonly, small-scale convective activity. Cold season precipitation is usually moderate in intensity, and relatively uniform over the watershed, while summer precipitation may be of high intensity and variable in space. Streamflow is dominated by the subsurface flow component; its response to precipitation is relatively damped in timing. The active groundwater aquifers are shallow and unconfined, so they respond to precipitation relatively quickly. The moderate climate and hydrologic responses of the Mahantango Watershed make the routine monitoring of its precipitation, streamflow, and groundwater levels relatively simple. Gburek (1977) has described the general hydrology of the watershed, and Urban (1977), the groundwater system.

The watershed is approximately 100 mi driving distance from University Park. The Center employs a full-time technical staff stationed at the watershed to oversee instrument installation, maintenance, and data collection associated with its research program.

NWRC DATA COLLECTION PHILOSOPHY

The NWRC is one of the newest Watershed Research Centers of ARS, so its staff had the advantage of being able to examine the research/routine data collection balance of other Centers when organizing its program. Long term, continous rainfall-runoff data from a variety of watershed sizes and climates were already being collected

at other Centers. Consequently, the NWRC decided not to become involved in its own extensive routine data collection effort requiring a substantial manpower commitment to both data collection in the field, and data reduction and analysis in the office. Two key decisions were made before any routine data collection was begun: 1) the majority of data collection activities would be in direct support of specific research hypotheses, thus, only minimal routine data would be collected, and 2) any routine data collection and reduction effort made was to be as automated as practical. Both these decisions have ramifications when discussing the quality of data collected at the NWRC.

EXTENT OF ROUTINE DATA COLLECTION

As at other Centers, two general classes of data are collected by the NWRC, data associated with specific research projects being conducted by the staff, and routine and continuing data collected in peripheral support of the projects and to monitor the watershed. The two types of data are kept distinct, and the utility of each is continuously evaluated. Research-oriented data is evaluated as to whether it has met the original project objectives; when it does, its collection is terminated. Routinely collected data is evaluated to ensure its providing some benefit by its collection; when it is not, adjustments are made. The requisite quality standards of research-justified data are usually dictated by the specific experimental objectives, and are described in individual research reports. These NWRC data will not be considered here. This report will discuss only the routine data being collected to support all NWRC research projects and to describe the overall hydrology of the Mahantango Watershed.

One factor in the choice of the Mahantango Watershed was a continuous record of streamflow at its outlet since 1930 (USGS Station 1-5555: East Mahantango Creek near Dalmatia, PA). However, the watershed contained no USWB raingages, and those surrounding it -- 7 gages from 4 to 25 mi away with lengths of record from 9 to 12 yrs -- showed mean annual precipitation ranging from 36 to 49 in. Having this type of background data from the watershed, the NWRC first installed a dense instrumentation network over the entire watershed to collect routine rainfall, runoff and meteorological data. The purposes of the network were: characterize general magnitudes and variabilities of the watershed's rainfall-runoff processes, indicate unexpected abnormalities in the watershed's hydrologic cycle, and develop a limited data base upon which to test future research concepts developed.

The original routine gaging network is shown in Figure 1. It contained 6 streamgage stations (3 natural control, G-R04, G-K27, G-M27; 2 broad-crested weirs, W-016, W-J30; and one broad-crested, sharp-crested tandem weir for both high and low flow control, W-E38), 8 meteorological sites, and 43 raingages, 8 of which were at the met sites. The network was designed to give relatively uniform raingage and met site coverage of the entire watershed, with emphasis on the subwatershed above G-K27. Streamgage placement sampled flow from the major subwatersheds and from a range of watershed sizes. This network operated from 1968 until mid-1972. Between 1972 and 1973, streamgaging stations W-016 and G-M27 were deactivated, and 2 met sites and 19 raingages were removed from the network,

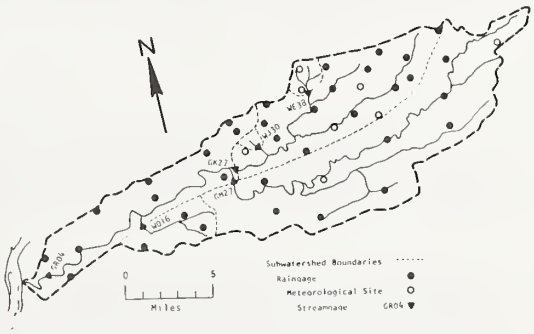
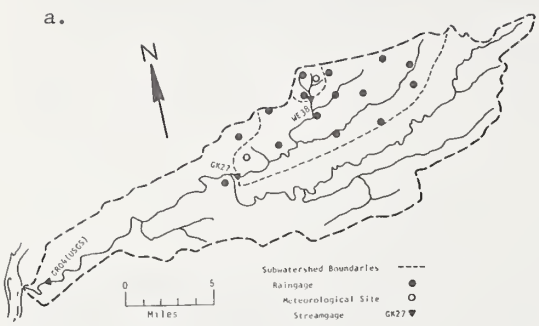


Figure 1. Routine Data Collection Network, 1968-1972.



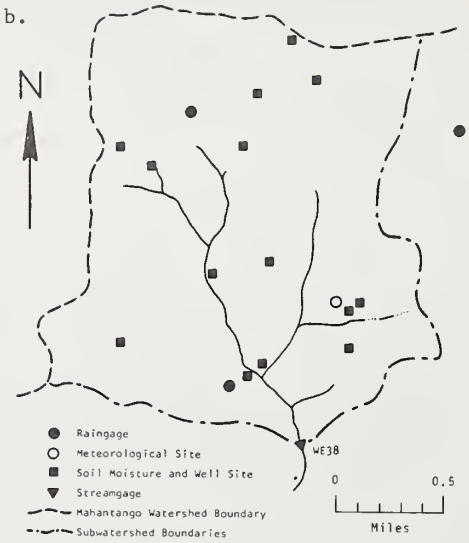


Figure 2. Routine Data Collection Network, 1977 - :
a. 44-sq.-mi. watershed G-K27;
b. 3-sq.-mi. watershed W-E38.

primarily from the subwatersheds above these streamgaging stations. Also during 1972 and 1973, 14 recording groundwater wells were installed for research purposes within the W-E38 watershed. There is a dearth of network-type routine groundwater data from small research watersheds, so these wells were also considered part of the routine data collection network.

In 1976, the NWRC staff felt that little additional benefit would come from continuing to monitor the entire 162-sq-mi watershed, so routine data collection outside of the 44-sq-mi watershed above G-K27 was discontinued. The G-K27 watershed was continued as a routinely monitored rainfall-runoff watershed, and the 3-sq-mi watershed above W-E38 was continued as a more intensively monitored watershed; rainfall, runoff, meteorology, groundwater and soil moisture data are being routinely collected. The present routine data collection network is shown in Figure 2a and b.

DATA ACQUISITION

In addition to raingages, meteorological sites are equipped with max-min thermometers, recording hygrothermographs, hand-read evaporation pans, and totalizing anemometers. Accepted methods are used for siting and maintaining these instruments, and all data collected from them are hand-reduced and stored on magnetic tape.

For recording routine precipitation, streamflow, and groundwater levels, the original NWRC staff committed to the automated data collection system made by the Fischer/Porter (F/P) Corporation. F/P gages record data in a modified binary digital format on punched paper tape. This record can be translated directly to magnetic tape for data reduction and analysis by computer. F/P gages are controlled by highly accurate electronic timers preset to record data at uniform time intervals. Raingages record accumulated depth of precipitation; stream and well water level gages record float-sensed relative depth of water in a stilling well or borehole.

The F/P gages are limited in sensitivity when compared to the more commonly used chart recorders. F/P raingages show only full 0.1-in changes in accumulated

precipitation, and stream and well level recorders show 0.01-ft changes in stage. Then, because the gages punch at uniform time intervals, changes are indicated only at the end of the time interval during which they occur. Yet, for a routine data collection network, the NWRC personnel feel that the F/P system's relative ease in gage servicing, increased timing accuracy over longer periods of time, and large reduction in workload associated with data translation, reduction, and final analysis, more than compensate for its lack in sensitivity. The original gage network, including gage descriptions and data translation procedures used, was described by Carr (1973). Specific aspects of the translation and data reduction procedures have changed since then, but the general approach remains the same. Only the collection and quality of routine F/P data will be described in this report.

2.1 Precipitation - Average precipitation within the Mahantango Watershed is just over 40 in/yr, and is nearly uniformly distributed by month. Measurable precipitation occurs on the average of one day in three.

Raingages were installed following recommended procedures regarding exposure and height. The gages had originally been tested for representative catch by the F/P Corporation, and limited testing was also done by the NWRC (Parmele, 1970). Since the Mahantango instrumentation was the first major concentrated F/P network, much of our earlier routine data collection effort amounted to field-testing the equipment. There were numerous minor problems with the initial gage design, both in the electronics and in the paper tape feed and punch mechanisms. These problems were remedied by NWRC personnel working in conjunction with the F/P engineers.

The F/P raingage is a weighing-type gage with an electronically activated digital recording system. Many of its maintenance procedures are similar to those used on chart-type weighing gages. Gages are weight-calibrated twice a year (spring and fall) to maintain accuracy, and the gage mechanisms are overhauled each spring. Oil is put in the catch bucket during the summer to retard evaporation, and anti-freeze is used in winter to eliminate freezing. At the 5-min punch interval used by the NWRC, battery life and maximum practical length of paper tape handled by the tape feed mechanism require that the gages be visited at 40- to 45-day intervals. During each visit, manually read gage accumulation is checked against the ending tape-indicated value and actual time checked against ending tape time. Differences are noted. The gage is emptied and a new tape is started, the timer is checked and reset if needed, and the battery is checked and replaced if needed. Gages are visited before their regularly scheduled time if problems are suspected, if they have been recently repaired, or if, because of a large amount of rainfall, their 20-in capacity is near to being exceeded.

2.2 Streamflow and Groundwater - Average annual streamflow from the Mahantango Watershed is approximately 40% of precipitation, about 18 in. Peak flow usually occurs in March and minimum flow during September. Storm hydrograph rises are generally controlled by precipitation intensities, and recessions are gradual because of the large baseflow component. On the long term basis, streamflow consists of about 70% baseflow and 30% direct runoff.

Streamflows are determined from continuously recorded water levels and rated channel control sections. The NWRC employs both natural control sections (formerly G-R04 and G-M27, and presently F-K27), and artificial controls (formerly W-016, a 3-ft, 5:1 broad-crested weir, and W-J30, a 1.5-ft broad-crested Virginia V-notch weir; presently W-E38, a 4-ft, 5:1 broad crested weir in tandem with a 1.5 ft, 90° sharp-crested weir). Stage is measured in stilling wells using F/P water level recorders. Rating curves were developed for the natural control sections using current meter techniques, originally over the full range of stage and thereafter spot-checked at varying stages to verify curve stability. Weir rating formulae were first determined using handbook procedures. Their applicability was then checked using current meter

techniques for larger installations or flows, and bucket-and-stopwatch rate-of-delivery techniques for smaller installations or lower flows. Where necessary, the rating formulae were modified based on these checks.

Natural control sections on the Mahantango Watershed are quite stable, since channel beds are usually cobble-armored or founded on rock, banks are moderately sloped and vegetated, and flows are seldom out-of-bank in the larger channels. Sediment concentrations are usually small; they do not affect rating curves. Weir ponds accumulate some sediment, and are usually cleaned once a year to maintain approach conditions. Stilling wells are kept ice-free during freezing weather using infrared heat lamps, and weirs are usually visited once a day to remove ice.

F/P streamgage recorders on the Mahantango Watershed punch at 5-min intervals, and are visited every 40 to 45 days. The same procedures described for the raingages are followed for streamgage tape changing and gage checks. During each visit, the stilling well inlet is flushed and the float tape is checked for proper positioning on the punch-drive wheel. At least once a year, and usually twice, all inlets are scrubbed and flushed with a high-pressure, high-volume pump, and the gage "zero" is checked against the weir notch or a surveyed bench mark (for the natural control sections). F/P streamgages are overhauled once a year.

Aquifers of the Mahantango Watershed are recharged when soil water deficits are met and soil water contents are raised by rainfall or snowmelt. Major recharge occurs throughout the dormant season, and isolated minor recharge events occur during the growing season. Streams are groundwater discharge areas, so depth to groundwater ranges from near zero in the vicinity of the streams, to over 50 ft on the watershed ridges. Groundwater levels are normally highest in March or April and lowest in September or October. Seasonal changes in levels range from less than 5 ft on the valley floors, to upwards of 25 ft at the watershed divide.

Groundwater wells were drilled 200 ft deep, and cased and grouted to bedrock. They have 6-in I.D. casing, and are monitored with F/P tide gages which are water level recorders with a spring counteracting the float rather than a counterweight. Groundwater level recorders are set to punch at 30-min intervals. Elevation of well casing tops were referenced to mean sea level by survey, and each recorder was set to an arbitrary datum. Transformation of relative height of water in the well, measured by the recorder, to its height above mean sea level is made during computer analysis of the translated paper tape record.

Well installations are visited every 60 to 70 days because of their 30-min punch interval. At each visit, standard tape changing procedures are followed, and the water level reading is checked with a hand-held, battery-operated water level indicator. Casing tops are periodically resurveyed.

2.3 Sedimentation - No sediment concentration data have been routinely collected on the Mahantango Watershed.

2.4 Water Quality - Water quality data have not been routinely collected on the Mahantango Watershed. However, a variety of water quality data have been collected for specific research purposes (Gburek and Heald, 1974; Gburek, 1977).

2.5 F/P Data Reduction - After removal from the instruments and initial hand-editing, F/P paper tapes are translated to magnetic tape. Appropriate software compresses the record by removing all redundant numbers (punches continuing at the same value due to no change at the gage) and identifies all remaining punch values with time and date, producing a "break point" type of record. Error codes are included with the final data indicating limitations, if any, on their use. Error codes identify conditions found in the field (i.e., gage malfunction, dead battery, etc.) or

during the data reduction procedure by computer (i.e., streamgage reading stuck at one value for extended periods of time, raingage catch decreasing, etc.). The "breakpoint" data from each individual paper tape are then merged into a continuous record of gage value, time, and error code, and stored on magnetic tape.

DATA QUALITY

Two aspects of data quality must be considered, the quality limitations caused simply by attempting to sample a hydrologic component, and the quality limitations resulting from the particular data collection system used by the NWRC, F/P instrumentation.

3.1 Precipitation - There are no major problems with the precipitation data routinely collected on the Mahantango Watershed. Care was taken when siting gages, and anamolies in catch checked by isohyetal analysis. Windshields are not installed on the F/P gages, so a slight deficiency in catch can be expected in winter months due to windy conditions during snowfall. However, water input from snow is less than 10% of the yearly total, so this deficiency is considered an acceptable limitation.

The relatively dense, uniform distribution of raingages on the Mahantango Watershed defines the areal distribution of both long-term and single event precipitation. The distribution of gages samples the ridges, where orographic effects increase long-term precipitation amounts, as well as the valley bottoms. The gage density adequately defines the spatial variability of typical summer thunderstorms. Gburek et. al. (1977) reported the network's representation of an extreme (>1000 yr return-period), localized (<28 sq mi) thunderstorm.

Timing within and between routine precipitation records is excellent, since the electronic timers activating the gage punch mechanisms are extremely accurate over long periods of time. However, the characteristics of the F/P raingage record, 5-min punch intervals and sensitivity to only 0.1-in changes, make interpretation of within-storm, short-term intensities subject to a high degree of uncertainty. This is considered an acceptable limitation for routinely collected data when compared to the F/P system's servicing, maintenance, and data reduction benefits.

3.2 Streamflow and Groundwater - Streamflow data on the watershed is considered good. All control sections were designed and installed, and are continuously rated and maintained, according to accepted procedures. Ratings at normal flow levels are good for both the natural control sections and the weirs, low flow ratings are only fair for the natural controls and broad-crested weirs due to section insensitivity, and high flow ratings for the natural sections are fair due to the relative lack of rating points. Both high and low flow portions of the rating curve are good for W-E38, the tandem weir. Sediment in weir ponds is removed yearly to maintain proper approach conditions. Some limitations exist for winter data due to ice on the weir notch or covering the stream; these are noted on the record.

Timing between streamgages, and between stream- and raingages, is excellent because of the accuracy of the electronic timers. F/P water level recorders are sensitive to 0.01 ft, so level definition is comparable to conventional water level recorders. The 5-min punch interval is sufficient to define the hydrograph peaks, as well as the rising and falling limbs, for the larger-sized watersheds gaged by the NWRC.

Quality of groundwater level data is excellent. Wells were installed so as to minimize leakage from the land surface to the bore hole, thus the changes recorded by a gage are considered to be actual changes in level of the local groundwater body. The F/P gage design, with the float tape wheel directly driving the punch wheel, makes

the gage reading an exact representation of the water level, even over large changes. The 30-min punch interval is adequate to define the time-rate-of-change in well levels, and finally, the timing of records collected is highly accurate.

3.3 Sedimentation - Nothing to report.

3.4 Water Quality - Nothing to report.

3.5 F/P Data Reduction - There are many gaps within all early routine F/P data; however, the instrumentation problems causing these were largely remedied within the first two years of data collection. The F/P system is unique in that when it is operating, it is usually operating properly. However, when the F/P gage malfunctions, nothing can usually be salvaged from the record, unlike a chart-type recording system which usually allows some aspects of the record to be salvaged when the gage malfunctions. Table 1 shows the characteristics of record collected by typical gages in the F/P system under the present service schedule of the NWRC. Unrestricted data implies no errors in value or timing; time-restricted data implies errors in timing only, with peaks or totals for the period of record available; restrictions on peak

Table 1. Quality of Typical F/P-Collected Hydrologic Data

	% Unrestricted Data	% Restricted Timing Only	% Restricted Peaks or Totals but Not Timing	% Restricted or Missing	Days of Record Represented
Raingages					
R-E37	85	12	0	3	4824
R-B37	75	24	1	<0.1	4786
Weir					
W-E38	75	14	0	11	4425
Wells					
A-D36-81-59	98	0	-	2	2922
A-B38-43-43	75	0	-	25	2546

or totals but not timing indicates that the gage continued to punch properly through the period of record, but the values punched were in error. The amount of time-restricted data could be reduced by more frequent visits to the gages. One problem remaining with the F/P system during extended periods of record collecting in rainy or humid weather is the propensity of the paper tape to stretch, sometimes resulting in mispunched data and loss of record. This problem could also be minimized by more frequent gage visits; however, this would defeat some of the advantages of the F/P system. The NWRC considers the amount of missing data shown in Table 1 a necessary and acceptable trade-off for the ease of operation, infrequent servicing, and efficient data reduction realized by the use of F/P equipment in a large-scale, routine hydrologic data collection system.

RECOMMENDATIONS FOR INSTRUMENT RESEARCH

A major problem facing the NWRC is the lack of proven instrumentation and techniques for sampling flow and hydraulic parameters in the subsurface domain of the watershed. We see the need to develop instruments and techniques to:

1. Characterize effective porosities and hydraulic conductivities within flow systems dominated by fractured materials.

2. Determine in situ hydraulic conductivity of subsurface materials.

3. Routinely sample and record flow direction and flow velocity in groundwater well boreholes.

4. Routinely sample and record in situ flow direction and flow velocity in the saturated and unsaturated zones of the watershed.

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Table 2. NWRC Data Acquisition System

Instrument Description	Problem Situations	Action Taken to Insure Data Quality
2:1 Precipitation:		
Watershed raingage network	Evaporation or freezing	Oil or antifreeze added to bucket
	Deficient winter catch	None
	Mechanical problems	Routine visits and yearly gage overhaul
2:2 Streamflow and Groundwater:		
Streamflow gage network	Sediment deposition in weir pond	Weir pond cleaned yearly
	Icing of weir notches and natural controls	Daily visits during freezing weather
	Stilling wells freezing	Infrared heat lamps installed
	Mechanical problems	Routine visits and yearly gage overhaul
Groundwater well network	Mechanical problems	Routine visits and yearly gage overhaul

Table 3. NWRC Data Quality Evaluation

Description of Current Stations	Number of Stations	Estimate of Data Quality	Special Problems and Comments
3.1 Precipitation			
F/P recording raingages	17	Good	5-min punch interval
3.2 Streamflow and Groundwater:			
Natural control section, F/P recorder	1	Good	5-min punch interval, high flow rating fair
Tandem weir, F/P recorders	1	Good-Excellent	5 min punch interval, 4 ft 5:1 broad-crested and 1.5-ft 90 deg. sharp-crested weirs
Groundwater wells, F/P recorders	14	Excellent	30-min punch interval, all in W-E38 watershed

GRASSLAND, SOIL AND WATER RESEARCH LABORATORY
TEMPLE, TEXAS

by

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1.0 INTRODUCTION

The hydrologic research at the Grassland, Soil and Water Research Laboratory was begun in 1936 by the Research Division of the Soil Conservation Service. Rainfall, runoff, and sediment measuring equipment was installed on 840 acres of government-owned land and on an adjacent larger area of privately-owned land near Riesel, Texas. Watersheds ranging in size from 3 acres to 5800 acres were instrumented. The research was transferred from the SCS to the Agricultural Research Service in 1954.

The research serves primarily the Blackland Prairie of Texas and surrounding land resource areas. The soils are highly calcareous, montmorillonitic clays with a high water-holding capacity and a high shrink-swell potential. The soils are also highly erodible. Major land uses include grain sorghum, cotton, cereal grains, forages, and pasture.

The primary mission of the research is to determine the hydrologic effects of conservation practices, management, and watershed characteristics. In recent years emphasis has been placed on developing quantitative descriptions of the physical processes of evapotranspiration, infiltration, surface runoff, and sediment and chemical movement. To pursue these objectives, measurements of rainfall, surface runoff, sediment and agricultural chemical concentrations have been made on selected watersheds.

2.0 DATA ACQUISITION

2.1 Precipitation

A raingage network of various densities has been maintained since 1936 on a 9-square-mile area. The network has included as many as 47 raingage sites. Observations at 5 sites on the government-owned area have been continuous since 1938, whereas much of the network on the privately-owned land was discontinued for a period beginning in 1943. Some of the raingages were re-activated after 1947. Details regarding raingage sites and periods of record are given by Knisel and Baird (1971).

A weighing-recording raingage and a standard non-recording raingage are located at each site. Each recording gage has a 6-hour time scale. The total amount of rainfall recorded by the recording raingage is often significantly different from the amount caught by the non-recording gage. The non-recording gage is used as the standard and the amounts recorded on the chart are corrected to the standard catch.

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The same method of precipitation data reduction has been used for the entire period of record. Breakpoint values are tabulated for all events greater than 0.10 inch. Only total precipitation is tabulated for storm events less than 0.10 inch and for freezing precipitation. Since 1960, the charts from the recording raingages have been tabulated using electronic chart reading equipment.

The average annual precipitation on the watersheds is about 33 inches. The largest monthly amounts occur in April and May with a secondary peak in September and October. Most of the precipitation is associated with frontal activity. Convective thunderstorms occur during the summer but generally do not produce large amounts of rainfall.

The relief of the watersheds is gently rolling with slopes ranging from less than 1% to about 5%. The maximum difference between raingage elevations is only 91 feet. The relief is not sufficient to cause orographic influences on precipitation.

The problems encountered at this location in making precipitation measurements are similar to those encountered elsewhere. The recording raingages are old and have many mechanical problems (Table 1). Many man-hours are required to provide adequate service to the weighing devices and clocks. The inaccuracy of the clocks causes difficulty in relating rainfall input to watershed output. The inaccuracy of the weighing-recording mechanism is corrected by frequent re-calibration and by correction to standard gage catch, as described above. The time errors are minimized by setting the clocks twice weekly and by marking the correct time when the charts are removed. All times are set to a master clock.

2.2 Runoff

Runoff from the research watersheds is almost entirely surface runoff resulting directly from precipitation intensities in excess of the infiltration capacity. Baird, et al. (1970) reported that 92% to 98% of the total watershed outflow occurred as direct storm runoff. The storm runoff events can have high peak discharge rates. Peak rates as high as 800 cfs have been measured from a 176 acre watershed. During these high flows, the flow depths change rapidly and sediment concentrations often exceed 20,000 ppm.

The remaining 2% to 8% of the flow that is not direct surface runoff is seepage flow from isolated perched water tables. This flow occurs at very low rates over long time periods.

The two types of flow (short duration high flow rates and long duration low flow rates) make it necessary to use runoff measuring devices that are capable of measuring both types. The measuring devices that have been used include H-flumes, broad-crested V-notch weirs, Parshall flumes, and field-calibrated artificial controls. All of these structures have stilling wells and water stage recorders. The Parshall flumes have Columbus-type weirs at the downstream end for measuring low flow rates. Continuous water stage recorders are maintained on both the flume and weir sections of the dual-control structures. As discharge increases, transfer must be made from the weir record to the flume record. When discharge rates increase rapidly, difficulty is experienced in finding matching discharge rates for the two controls. Clock and recorder errors exaggerate the problem. Frequent time checks and good recorder maintenance are required to minimize the problems. The runoff instrumentation is described in more detail elsewhere (SCS, 1942).

A number of problems have arisen in making runoff measurements on the research watersheds (Table 1). The high shrink-swell potential of the soil causes the structures to shift as the soil wets and drys, resulting in discrepancies between the stage recorder readings and the actual depth of flow. The problem is overcome by occasionally re-surveying and zeroing the recorders. However, the procedure is time consuming.

Some of the artificial controls have unstable ratings above a given stage due to backwater caused by downstream vegetative growth or sedimentation. For most events, current meter measurements must be made at those structures when the depth of flow is above a specific stage. Occasionally channel re-shaping is required.

The need to measure both rapidly changing stages during storm events and sustained low flow rates requires that two recorders with different time scales be placed on each runoff structure. On most structures, a stage recorder with a 6-hour time scale is used to record the rapidly changing stages and a 192-hour time scale is used for the sustained low flows.

Sediment deposition on the runoff measuring structures is one of the more serious hinderances to making accurate runoff measurements. Sediment clogs the intakes to the stilling wells and causes errors in the stage record. Sediment also changes the cross section of the channel above the control. These problems are particularly acute with the broad-crested V-notch weirs. The sediment must be removed after each runoff event, and the stilling wells must be cleaned periodically.

The Parshall flumes have demonstrated excellent sediment self-cleaning characteristics. These structures are 6 feet to 15 feet wide at the narrowest point. When they were built (1930's), considerable sediment was deposited during runoff events between the flume section and the weir used for low flow measurement. After some minor modifications, only minor amounts of sediment were deposited on the structures.

2.3 Sedimentation

The soils on the research watersheds are predominately clays. Consequently, the sediment transported by runoff is 70% to 85% clay (Knisel and Baird, 1970). Only a minimal amount of eroded material is transported as bed load. The small particle sizes also result in relatively uniform sediment concentrations in a vertical stream section. Typical sediment concentration distributions in vertical sections are given by Knisel and Baird (1970).

Sediment samples are obtained at the runoff measuring structures during runoff events. During the early years of the watershed studies, an open-mouth pint bottle with a long-handled holder was used to obtain dip samples from the flow. DH-48 samplers were used beginning in 1960. Chickasha-type pumping samplers are now used on all stations where sediment samples are obtained.

Although there are still many problems associated with sediment measurement, the pumping samplers have greatly simplified the sampling process. The small particle size and uniform sediment concentration in the vertical make the pumping samplers well suited for sediment sampling on these watersheds. The automatic samplers make it possible to obtain frequent, early-event samples. This was not possible with manual techniques. With careful maintenance, the automatic samplers have proven to be very reliable.

2.4 Water Quality

Plant nutrient data are collected on a continuing basis on several watersheds. Nitrogen and phosphorus concentrations in runoff have been collected since about 1970. Herbicide concentrations have been measured periodically for specific studies. Most of the water quality samples have been obtained with the pumping samplers. When both water quality and sediment are to be analyzed, the samplers are programmed to obtain extra samples for water quality, or individual samples are split to provide samples for both analyses. The water quality samples are refrigerated until they can be analyzed. The problems with obtaining water quality samples are much the same as those described above for sediment.

3.0 DATA QUALITY

3.1 Precipitation

The quality of the percipitation data is good considering the normal limitations of precipitation measurement, i.e., wind effects, limited areal coverage, etc. (Table 2). The total precipitation amounts for an event should be particularly accurate. The time distributions of precipitation are of lesser quality than the amounts because of clock inaccuracies. The dense gage spacing on the watershed and lack of orographic effects provide for adequate description of spatial patterns.

3.2 Runoff

Most of the runoff devices are well suited for this location. The data obtained are of good to excellent quality (Table 2). The Parshall flumes, although expensive and complex to build, are particularly well suited to the wide range of flow rates and high sediment concentrations that are experienced. The artificial controls with current meter ratings have also been used successfully except where channel conditions cause an unstable rating. The V-notch weirs provide data of questionable quality because of sediment deposition upstream from the control during runoff events.

3.3 Sedimentation

The automatic pumping samplers provide an excellent technique for sampling the fine materials transported in runoff at this location. The samplers have substantially improved the quality of sediment data by increasing the number of stations that can be sampled and by making it possible to obtain samples early in the runoff events when sediment concentrations are highest. The samples obtained are thought to be representative of the average concentration in the vertical due to the relatively uniform concentration with depth in these streams. However, the larger streams do have substantial sediment concentration variations across the channel. Sampler modifications are needed that would provide for sampling these horizontal variations.

3.4 Water Quality

Water quality samples are obtained in conjunction with the sediment sampling activity. Nitrogen and phosphorus samples are routinely obtained at eight stations (Table 2). Herbicide samples are obtained for short periods following application on selected watersheds. These data are, in general, of good quality. Some data quality problems may be caused by exposure of the samples to high temperatures in the field before the samples can be refrigerated and by extended storage before analysis.

4.0 RECOMMENDATIONS FOR INSTRUMENT RESEARCH

1. Develop automatic sampling methods that will integrate the horizontal variations in sediment and chemical concentrations in a stream.
2. Determine the effects of sampling by pumping samplers on sediment concentrations and particle size distributions.
3. Develop methods of synchronizing the time recording of rainfall and runoff events.
4. Develop methods of accurately measuring flow depths during rapidly changing flow rates.
5. Develop accurate methods of measuring flow rates at stations affected by channel backwater.
6. Develop practical means of relaying rainfall and runoff data to a central location.

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Table 1. Data Acquisition System

Instrument description	Problem situation	Action taken to insure data quality
2.1 Precipitation		
Weighing-recording raingage	Calibration drift	Frequent re-calibration and correction to standard non-recording raingage catch.
	Clock inaccuracy or failure	Twice weekly clock setting and frequent clock repair and/or exchange.
Watershed raingage network	Areal representation	Dense network provided.
2.2 Runoff		
Runoff structures	Shifting due to soil swelling	Frequent level checks.
	Sediment deposition on structure	Use self-cleaning type of structures and/or remove sediment after each event.
	Unstable ratings caused by channel conditions	Current meter measurements and/or channel maintenance.
	High peak discharge and sustained low flows	Dual controls with two stage recorders on each control having different time scales.
2.3 Sedimentation		
Suspended sediment sampling	Inadequate samples during early part of event	Automatic pumping samplers installed.
	Pump sampler failure	Regular between-event maintenance and within-event checking.
	Timing of sample with runoff	Concurrent mark on runoff chart.
2.4 Water Quality		
Chemical concentrations	Deterioration during storage	Refrigerated until analyzed.
	Slow laboratory analysis	Samples composited for each event to reduce number of samples.

Table 2. Data Quality Evaluation

Description of current stations	Number of stations	Estimate of data quality	Special problems and comments
3.1 Precipitation			
Recording gages	30	Good	Non-recording gage located with each recording gage. Recorded amounts corrected by ratio of non-recording gage catch to chart record.
3.2 Runoff			
3-ft. H-flumes	5	Excellent	Approach must be cleaned periodically.
Parshall flumes with weir controls for low flows	7	Excellent	Structure shifting due to soil swelling. Requires two stage records.
Artificial controls	4	Good	Requires periodic current meter calibration. Intake sediment removal required.
V-notch weirs	4	Fair	Upstream sediment removal required.
3.3 Sedimentation			
Chickasha automatic pumping samplers	15	Excellent	Should be checked during event for malfunction.
3.4 Water Quality			
Nitrogen and phosphorus concentrations	8	Good	One weighted composite sample obtained for each station and each event. Standard analytical procedures used.

SLEEPERS RIVER RESEARCH WATERSHED, DANVILLE, VERMONT

H. B. Pionke, R. L. Hendrick, and B. J. Chamberlin

INTRODUCTION

The Sleepers River Research Watershed was created in 1957 to provide additional knowledge on the physical behavior of natural watersheds, and to solve specific hydrologic problems of the New England area, e.g. runoff prediction and control for smaller rural watersheds. Located in northeastern Vermont, this watershed is typical of the formerly glaciated upland regions that provide much of the fresh water used by farms, industries, and cities of the northeast (Figure 1).

Figure 1. Typical Streamgaging (W-1) and Meteorological Site (R-21).

During the first few years of the watershed's operation, the emphasis was on developing adequate hydrologic and meteorologic measurement networks and establishing a sound data base. After about 10 years, emphasis shifted to analysis and interpretation of data, and to research on the physical and biological processes most important to the water resources and environmental quality problems of New England. However, considerable resources were still directed toward data collection and processing until the closing of the Research Watershed on September 1, 1979. The specific research projects included studies of watershed geology and hydrology, precipitation characteristics, snow hydrology, groundwater accretion and movement, land use effects on runoff, channel hydraulics and water quality.

Data collected from the Sleepers River Research Watershed can be classified as: (i) routinely collected data, primarily hydrologic and meteorological data collected from a gaging network, (ii) support data used to better interpret the hydrologic and meteorological data; and (iii) data collected as part of specific research

studies. It is toward data group (i) that this discussion is directed. The erosion, sediment transport and water quality studies were research oriented, often using special data networks and custom equipment designed to achieve short-term research (Pionke et al., 1982).

DATA ACQUISITION PROGRAM

2.1 Precipitation - The average annual precipitation ranges from 35 to 50 in, depending on elevation. The seasonal distribution of precipitation is approximately: spring - 28%, summer - 32%, fall - 22%, winter - 18%. Average precipitation exceeds average evapotranspiration for all months except June, July and August. From late November to late March, a permanent winter snowpack builds up, normally to 8 to 12 in water equivalent. The combined snowmelt (8 to 12 in water equivalent) and rainfall occurring from late March to early May causes more than 50% of the annual runoff. Thus, water input to the watershed's surface during winter which averages less than 20% of annual precipitation, increases to several times the precipitation in April (Hendrick and DeAngelis, 1976). Because the time distributions of precipitation and water input differ drastically, snow courses were included with the precipitation gage network.

Spatially, precipitation network requirements for New England may be less restrictive than for the central and western U. S. Large-scale storm systems with moderate intensity gradients produce most precipitation from October through May, while small scale convective systems dominate in summer. There are good intergage correlations of storm precipitation even in summer and over the elevation range of the watershed (Hendrick and Comer, 1970). Increased precipitation with elevation (~50% per 2000 ft. elevation increase) results primarily from increased storm intensity and secondarily from duration (Hendrick and Dingman, 1978). The precipitation network (Figure 2) included 35 sites that contained weighing, recording raingages; 20 of these sites had snow courses and air temperature recorders. Gage network density varied somewhat but closely approximated 1 gage per 1.3 mi^2. The general nature of the precipitation climate and the data network has been described by Engman and Hershfield (1969) and Hendrick (1971).

Initially, a variety of recording raingages and siting conditions were compared, including orifice size, orifice height and the effectiveness of shielding. Belfort, Freiz and Universal raingages were used. In a test against the 12 in diameter orifice, the 8 in diameter was found adequate and became the standard unit used throughout the watershed. The gages were originally set to an orifice height of 42 in above ground surface, then raised to 72 in orifice height during snow seasons from 1964 to 1973 to minimize the effect of snow drifting. They were left at this 72 in height year round from 1973 to 1979. Raingage shields increased snow catch by an 18% average in wind-exposed, open areas. Gage sites on exposed hill tops, near cliffs, in woods or exposed to severe or turbulent winds, more frequently failed or gave questionable readings than those not so subjected. Raingage servicing was especially important in winter. Clock stoppage, ink pen failure, snow bridging over the orifice, snow blowing from tree tops and the accumulation and later melt of freezing rain on the inside gage wall were some problems (Table 1). Service frequency was weekly and included antifreeze and evaporation suppression techniques. Calcium chloride solution was added to prevent freezing while oil was added during the summer to minimize evaporational losses. The raingage funnels were removed each winter to reduce snow and ice hangup in the gage receiver. Major gage overhauls were performed annually with the units being recalibrated routinely on site. Snow course data were collected from a mowed, fenced, 10 by 30 ft. plot. These sites were chosen to avoid snow drifting and resurfacing seepage -- the latter being a common problem near streams, low spots, and at slope inflections. The snow depth and density sampling line (five cores per sampling) was sequentially moved across the plot to insure sampling of the undisturbed pack. After 1967, 3 in diameter fiberglass tubes were substituted for the 2 in diameter Sierra sampling tubes, which

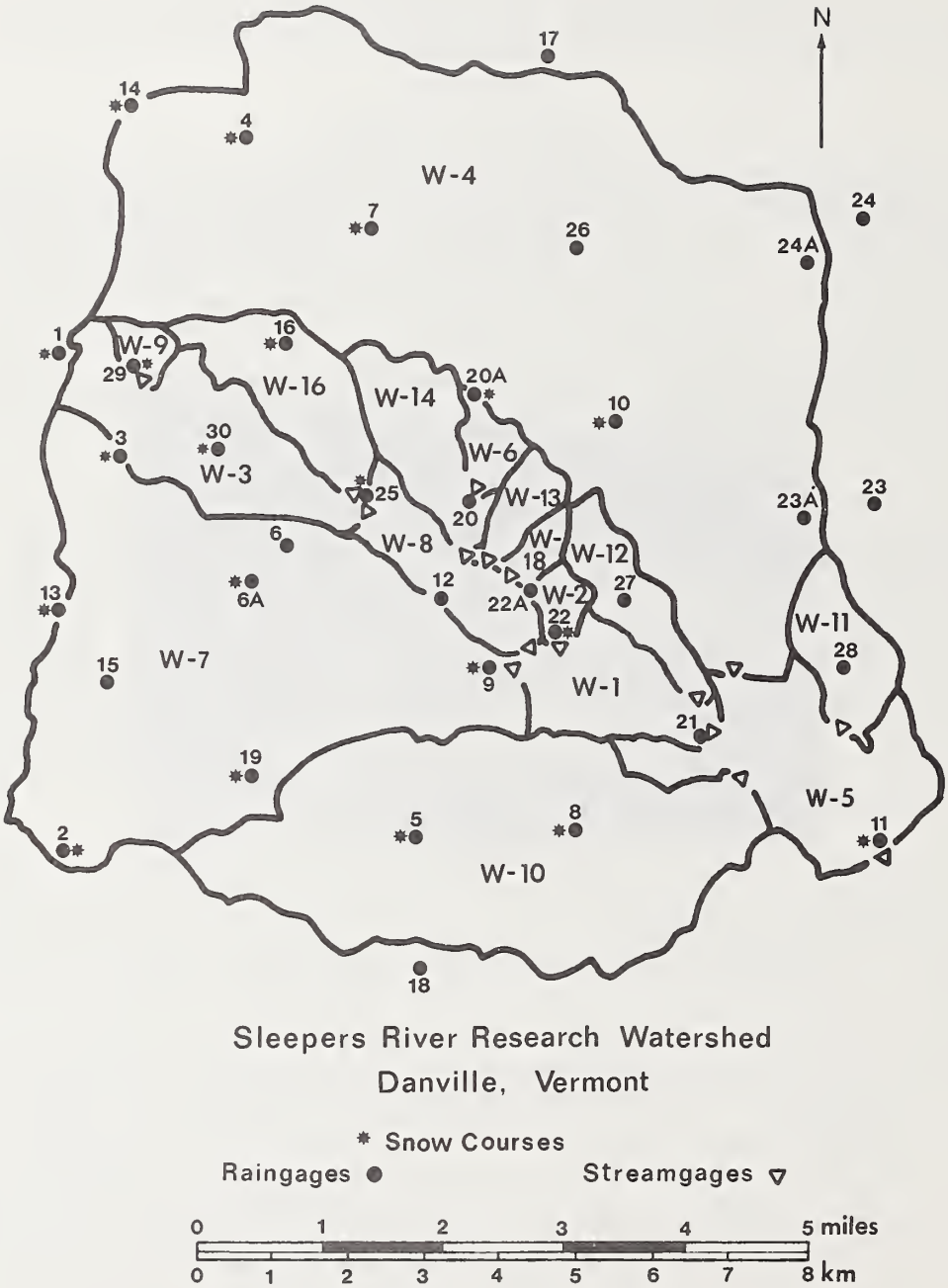

Figure 2. Location of Meteorological Sites, Stream Gages and Sub-watershed Boundaries of the Sleepers River Research Watershed, North Danville, Vermont.

Table 1. Data Acquisition System

Instrument Description	Problem Situation	Action Taken to Insure Data Quality
2.1 Precipitation:		
General	Catch altered due to insufficient or extreme exposure.	Use of wind shields, site transfer or modification, e.g., expanding clearings and/or elevating gages.
Watershed Raingage Network	Clock (spring driven) and pen (chart) malfunctions	Improved and increased maintenance, especially under extremely cold, windy or wet conditions. Replaced instruments that failed frequently.
	Evaporation and ice.	Oil and antifreeze ($CaCl_2$) used in gages.
	Snow bridging and ice hangup in receiver.	Remove raingage funnel each winter.
	Mechanical problems.	Weekly servicing, routine recalibrations, and annual overhauls.
Snow Course	Errors associated with sampling slush, ice, thin snow, and fine-grained, granular snows	Change in sampling equipment and methods to reduce frequency of problem.
	Representativeness of site.	Located and relocated to sites not subject to drifting snow or surfacing seepage.
2.2 Runoff/Streamflow/Groundwater:		
Streamflow Gaging Network	Clock (spring driven) and pen (chart) malfunction	Improved and increased servicing and maintenance procedures. Replaced instruments that failed frequently.
	Sediment deposition in weir approach.	Sediment removed annually or more often dependent on filling rate.
	Severe icing.	Heaters installed at weir notch and in stilling wells. Generally, heaters at the weir notch ineffective, requiring manual removing of ice daily.
2.3 Sedimentation:		No entry.
2.4 Water Quality:		No entry.

improved sampling accuracy under conditions of heavy ice, slush, thin snow, and especially when the snowpack contained thick ice lenses.

The snow course was sampled weekly, more frequently during spring snowmelt. Snow pillow and melt lysimeter data were collected continuously by NOAA at one site on the watershed (Anderson, et al., 1977).

2.2 Runoff/Streamflow/Groundwater - Runoff averages about 12 in per yr. at lower elevations and 20 in per yr. at the higher elevations, with snowmelt usually producing the annual peak runoff event. Up to 50% of the annual runoff occurs during the spring snowmelt period. One reason is that the groundwater and soil water storage normally becomes filled in spring, which causes all subsequent water input (rain and snowmelt) to become runoff. Runoff also has a large "interflow" or quick-response subsurface return flow component (Dunne, 1970). As determined by hydrograph separation techniques, 60 to 80% of the annual runoff is baseflow.

Runoff was measured for the 16 subwatersheds from a combination of known stage and control-point geometry. The control points were either flumes or weirs. Five weirs were operated with a dual gage system (large weir, small weir) for more accurate estimates of both low and high flow. For the dual weir installations, the stage measurement was switched from the high to the more sensitive low flow weir when the stage in the large weir was less than 0.8 ft. Stage at all gaging sites was continuously recorded by a standard float-activated, strip chart recorder with all floats being located in stilling wells. The recorders were routinely calibrated against staff gages, and by periodic check against the weir notch elevation by surveying transit. The recorder stage was checked at least twice yearly by transit survey with the reading being set according to the surveyed depth of water in the weir pond. Not all sites had continuous staff gage records because of their loss or physical destruction by ice movement during ice break-up periods. Weir notches were physically deiced at least daily. Gas infrared heaters were used to prevent ice buildup in the low flow weir notches with mixed success. Stilling wells were maintained ice-free by use of gas heaters or electric heat lamps. The intake pipes to the stilling wells were flushed free of sediment periodically. Weir pools were dredged as needed, usually no more than yearly. Stage-discharge relationships were developed by i) current meter methods at most moderate to high flow rates and ii) measured delivery rate of water volumes over the weir at very low flow rates. Groundwater measurements were not made routinely, thus no records are available. Relative humidity, air temperature, pan evaporation, wind speed, soil moisture and soil temperature records were collected at selected locations for most or all of the runoff record.

2.3 Sediment Concentrations - These were not measured routinely but only as part of two short term special studies (Kunkle, 1971a, Kunkle and Comer, 1972).

2.4 Chemical Concentrations - These were not measured routinely but only as part of short term special studies into road salt (Kunkle, 1971b; 1972), dissolved solids (Hall, 1971; Kunkle and Comer, 1972), and fecal bacteria sources and transport (Kunkle, 1970a,b; 1979). Stream temperature was monitored continuously at six sites, from 2 to 6 years depending on weir site.

DATA QUALITY PROBLEMS

3.1 Precipitation - Data quality improved substantially early in the program as a result of improvements in instruments, procedures, and maintenance practices and schedules to correct problems (Table 2). Winter maintenance was greatly improved over the first five years. However, the severe winter climate caused some missing or poor quality data, especially when gaging sites became temporarily inaccessible, or were subjected to severe cold, winds, drifting snow or freezing rain. Raingages were

Table 2. Data Quality Evaluation

Description of current stations	Number of stations	Estimate of data quality[1/]	Special problems and comments
3.1 Precipitation:			
Recording Gages Unshielded	25	Fair - snowfall Good - rainfall	Later record of better quality as relocation and wind shields improved snow and rain catch of sites where problems were evident.
Shielded	10	Good to excellent rainfall Fair to good - snow	
Snow Courses		Fair to good	First five years of record is generally of fair to good quality depending on the site. Eliminating problem sites and correcting sampling procedures upgraded the snow course record to good by 1967.
3.2 Runoff/Streamflow/ Groundwater:			
Individual Broad Crested V-Notch Weirs		Excellent	Initial record generally fair to good. Subsequent record good to excellent, especially at low and middle flow rates. Weir and stilling well icing, clock and pen problems were much better controlled after the first few years.
90°	2		
60°	1		
30°	5		
10:1	1		
20:1	1		
Individual Sharp Crested V-Notch Weirs (90°)	1	Good to excellent	
Dual V-Notch Weirs - 30° Broad Crested in series with 90° Sharp Crested	5	Good to excellent	Flow computed on basis of 90° weir below 0.8 ft. stage and on the basis of 30° weir above 0.8 ft. stage.
3.3 Sedimentation:			No entry
3.4 Water Quality:			No entry

[1/] Excellent = $\pm$ 5%
Good = $\pm$ 10%
Fair = $\pm$ 20%
Poor = $>$ 20%

shielded, snow courses were moved away from surface seeps, and both were moved to normally exposed and/or drift free areas where appropriate. Because of high intergage correlations, even over large elevation differences, network density was not a major issue. Also, because of the large baseflow component (60 to 80%), the relatively stable flows, and the dominance of snowmelt, coincident timing between gages is not as critical an issue as in parts of the U. S. where flows are unstable and dominated by direct runoff. The primary problem was measuring and estimating water input through the snowmelt period.

3.2 Runoff/Streamflow/Groundwater - Similar to precipitation, the data quality problems decreased rapidly over the first few years because of improved procedures, maintenance and instrumentation. Streamflow measurements during snowmelt were usually very good to excellent because of the relatively stable high flow rate. The weirs were rated mostly during these more stable flows using standard U. S. Geological Survey methods. One problem was to measure quick (interflow) and total subsurface return flow in a system where classic hydrograph separation techniques may provide the least accurate estimates of surface and subsurface return flow for any place in the U. S. Because the watershed fully recharges during most springs, the hydrologic budget and the rate of water transfer among hydrologic components is more likely to be easily and accurately measured here than elsewhere, especially if the subsurface return flow component can be accurately measured. The weirs were constructed with deep wing and cut-off walls, usually down to bedrock, to minimize the unmeasured subsurface flow. Flow measurements during winter and early spring were usually accurate or correctable under stable flow conditions because of daily ice removal procedures. Where flow peaks or unstable flow rates were associated with excessive ice buildup or ice jams, the record is much less accurate.

3.3 Sediment Concentrations - Suspended sediment concentrations of the larger New England streams are generally quite low, and from the perspective of field instrumentation and hydraulics, are not considered as severe a problem as in the central and western U. S. At the smaller spatial scale, suspended sediment concentrations can be high, especially from strip mined, dredge spoil, clear cutting, construction sites or sites characterized by poor farming practices,by very erosive soils, or by substantial gully, stream bank and/or roadside erosion. Generally, in New England the sediment transport issue is more likely to be viewed from the perspective of increased pollutant transport and reduced food production potential, than from the mechanical filling of stream channels.

3.4 Water Quality - Water quality, especially nutrient, pesticide, dissolved oxygen, biological oxygen demand, microorganisms, toxics and temperature are considered problems in select areas of New England. Selected water quality results are published (2.4). The stream temperature data is good quality.

RECOMMENDATIONS FOR INSTRUMENT RESEARCH

The experience gained in this cold climate watershed showed a need for improved methods and instrumentation in the following areas:

1. Develop low cost and reasonably accurate methods for measuring water input (rate of snowmelt and precipitation input to the soil surface) at a point and spatially.

2. Develop instruments and methods for measuring "interflow" or the quick subsurface return flow component.

3. Develop methods to remotely measure snow depth and water equivalent.

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CHAPTER 'B' BLACKSBURG, VIRGINIA

By James B. Burford[1]

1. INTRODUCTION

During the mid 1950's, concern related to the ever-increasing demand for water supplies, paralleled with the continuing threat of flood damage from excessive amounts of water, emphasized the need for additional hydrologic information from small (less than 10 sq. mi.) agricultural watersheds in Virginia.

Commitments were made by the Agricultural Research Service (ARS) and the Soil Conservation Service of the Department of Agriculture and the Virginia Agricultural Experiment Station to cooperatively initiate and support a watershed hydrology research project with the following objectives: (1) to identify, measure and relate the physical characteristics of soil, topography, geology, land use and cover conditions, existing in experimental watersheds, together with the climatic conditions to water yields and peak discharges; and (2) to determine ways of representing the factors of climate, soils, topography, geology, land use and cover conditions so that they may be used in the prediction of water yields and peak discharges on ungaged watersheds. These cooperative efforts culminated with the selection and instrumentation of ten experimental watersheds ranging in size from 182 to 3054 acres (73.68 to 1236.3 hectares).

Primary selection criteria dictated that the experimental watersheds be representative of as many of the various problem areas of Virginia as possible and that each must be located above an existing rateable flow control structure. Nine of the selections are above highway box culverts and one terminates at a concrete dam. (figs. 1 thru 5). Instrumentation, for precipitation and streamflow measurements, was first completed on three of the watersheds during mid-1957 with final completion of the last two by September, 1960 (see table 1) All ten studies were operated through 1968 at which time five were discontinued and the Virginia Agricultural Experiment Station assumed responsibility for operation of the remaining five.

Project headquarters was located in the Department of Agricultural Engineering, Virginia Polytechnic Institute, Blacksburg, Virginia, therefore the location name. Location, basin characteristics, cover and cropping conditions information, together with data summaries are included in publications (1)[2] and (2).

2. DATA ACQUISITION

Continuous recording instruments were used to obtain precipitation and streamflow data for all watershed and for evaporation, humidity, and temperature on the Crab Creek (1307) watershed. Local, paid, observers were used to service the instruments, at least once each 7 days, and mail the charts to headquarters, for nine of the watersheds. Project personnel serviced the instruments on the Crab Creek watershed which is located about 10 miles from project headquarters. Routine inspection visits

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[1] Supervisory Hydrologist, Water Data Laboratory, Plant Physiology Institute, Beltsville Agricultural Research Center, Beltsville, MD.

[2] Underscored numbers in parentheses identify references cited and listed at end of chapter.

Figure 1.--Flow measuring station below the Throne Ck. (13006) watershed. Concrete dam with 52' rectangular notch for high flows and a broad crest V-notch for low flows.

Figure 2.--Standard single barreled culvert (with V-notch weir added) flow measuring station below Pony Mt. Br. (13102) watershed. Similar to flow controls below 13009, 13013 and 13015.

Figure 3.--Standard double barreled culvert (with V-notch weir added) flow control below Chub Run (13013) watershed. Similar to the flow control for Crab Ck. (13007).

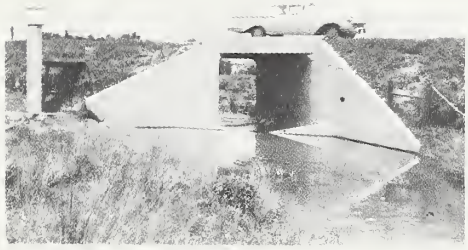

Figure 4.--Single barreled culvert with skewed entrance condition (with V-notch weir added) flow control below the Brush Ck. (13008) watershed.

Figure 5.--Double barreled culvert with mis-aligned approach conditions (with a unique designed V-notch weir added) flow control below Little Winns Ck. (13010) watershed.

Table 1.--Complex Watersheds - Blacksburg, VA

Location Name (Ident. No.)	Starting Dates (mth./day/yr.) Records	With modified controls	Flow Control types 1/	Flow Rates 2/ Cfs (in/hr)	Area Acres (Hectares)
Thorne Ck. (13006)	5/20/57	6/24/61	Concrete Dam (modified V-notch)	1.725 (.00056)	3,054 (1,236)
Crab Ck. (13007)	7/19/57	6/04/59	Std DBC DVN	.872 (.00110)	786 (318.1)
Brush Ck. (13008)	8/01/57	8/01/57	SBC(Skewed) SVN	____	893 (361.4)
Powells Ck. (13009)	1/01/58	6/19/59	Std. SBC SVN	.506 (.00276)	182 (73.7)
Little Winns Ck. (13010)	1/01/58	5/20/60	Std. DBC SVN (offset)	.677 (.00046)	1,471 (595.3)
Rocky Run Rb. (13011)	4/01/58	8/04/59	Std. SBC SVN	.588 (.00105)	555 (224.6)
Pony Mt. Br. (13012)	5/09/59	8/01/59	Std. SBC SVN	.403 (.00208)	192 (77.7)
Chub Run (13013)	9/23/59	9/23/59	Std. DBC DVN	____	2,023 (818.7)
Fosters Ck. (13014)	9/01/60	9/01/60	Std. SBC SVN	____	389 (157.4)
Chestnut Br. (13015)	8/31/60	8/31/60	Std. SBC SVN	____	1,058 (428.1)

1/ Std. DBC = Double Barreled Culvert, Standard Design.
Std. SBC = Single Barreled Culvert, Standard Design.
DVN = Double V-Notch.
SVN = Single V-Notch.

2/ Discharge rate data quality:
Poor ($\pm$ 20%) for rates $\leq$ rate shown for periods prior to control modification date.
Good ($\pm$ 10%) for rate $>$ rate shown for periods prior to control modification and for all flows after control modification.

Table 2.--Precipitation Stations - Complex Watersheds
Blacksburg, VA

Watershed Name (Location No.)	Precipitation Gage Station 1/ Ident.	Data File Code	Watershed Name Location No.	Precipitation Gage Station 1/ Ident.	Data File Code
Thorne Ck. (13006)	R-1	P04R01	Rocky Run Br. (13011)	R-1	P26R01
	R-2	P05R02		R-2	P27R02
	R-3	P06R03	Pony Mt. Br. (13012)	R-1	P28R01
Crab Ck. (13007)	R-1	P07R01		R-2	P29R02
	R-2	P08R02	Chub Run (13013)	R-1	P30R01
	R-3	P09R03		R-2	P31R02
	R-4	P10R04		R-3	P32R03
	R-5	P11R05	Fosters Ck. (13014)	R-1	P33R01
Brush Ck. (13008)	R-1	P19R01		R-2	P34R02
	R-2	P20R02	Chestnut Br. (13015)	R-1	P35R01
Powells Ck. (13009)	R-1	P21R01		R-2	P36R02
	R-2	P22R02		R-3	P37R03
Little Winns Ck. (13010)	R-1	P23R01			
	R-2	P24R02			
	R-3	P25R03			

1/ Precipitation Stations Identified as "R-1", equipped with 192 hr. time scale clocks-charts. All others operated with 12 hr. charts or paper tape recorders with 5 minute punch intervals.

were made to all instruments by projects personnel with special visits made on notice from the observers.

2.1 Precipitation Data

Five of the watersheds were instrumented with two precipitation measuring stations each, while three stations were used on each of the four largest areas. The Crab Creek watershed had four precipitation stations for most of the period of record with a fifth operating for a short time, table 2 (3).

One precipitation station, identified as R-1, on each of the watersheds operated with 192 hour chart while all other gages operated with 12 hour charts. Each station was equipped with a "standard" can type gage.

Punch tape recorders with five minute recording intervals, were installed at three of the Crab Creek (R-3, R-4 and R-5) precipitation stations January 1967. These gages operated parallel to the conventional chart type recorders at the R-3 and R-4 stations until early 1969, when they were removed. A punch tape recorder only was used at the R-5 gage.

All precipitation data obtained with the 12 hour time scale charts and the punch tape recorders were converted to digital form and computer processed. Gaps which occurred in the records obtained with the punch tape recorders, due to recorder malfunctions, were filled in with data obtained with the chart type recorders. Parts of the records obtained with 192 hour (weekly) charts have been converted to digital form and processed. Data obtained with these weekly charts are valid only for accumulated (daily) amounts.

Precipitation data in "breakpoint" form through the full periods of record are on file with the Agricultural Engineering Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Data for periods of record through 1972 are included in the ARS water data bank maintained by the Water Data Laboratory (WDL). Data for the later periods of record will be included in the ARS data bank as they become available.

2.2 Streamflow Data

Continuous streamflow depth records were obtained for the complete periods of records for all ten watersheds. Chart type records with 24 hour time scales were used for periods of records through 1966 and for the period following early 1969. Late in 1966 (operational Jan. 1, 1967) through part of 1969, all ten streamflow stations were equipped with punch tape recorders operating with five minute time intervals and recording flow depths to the nearest 0.01 ft. The chart type recorders, converted to weekly time scales were continued as backups. Occasional gaps in the punch tape records which occurred due to recorder malfunctions, were filled in with chart recorded data.

All of the streamflow records have beem converted to digital form and computer processed. The data, in breakpoint form, for the complete record are on file with the Agricultural Engineering Department at Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Data for the periods of records through 1972 are included in the ARS water data bank maintained by the WDL. Data for the later periods will be included in the ARS data bank as they become available.

Modified existing structures were/are used for flow controls at each of the ten measuring stations. Nine of these are highway box culverts and one (Thorne Creek-

1306) is a 52 ft. long concrete dam with a 20.4 ft. wide by 1.55 ft. deep rectangular notch. The rectangular notch was modified to a standard broad crested triangular weir with 5:1 side slopes, June 24, 1961. (fig. 1) (4).

All nine box culverts were modified with the addition of Virginia V-Notch weirs (4) and (5) to improve the accuracy of low flow measurements (figs. 2 thru 5). Six of the stations, including Thorne Creek, were operated for periods prior to the V-notch installation, see table 1.

Rating table information for five of the culvert-V-notch combination stream gaging stations was made available from model studies conducted at the ARS Outdoor Hydraulic Laboratory at Stillwater, Oklahoma. The model studies included two single and one double barreled culverts of standard design, figures 2 and 3, respectively, and two with non-standard design conditions, a single barreled, with skewed entrance, fig 4, and a double barreled with unique approach channel conditions, fig 5. This model information was used as the basis for developing rating curves for the other four stations using standard designed box culverts.

3. DATA QUALITY EVALUATION

3.1 Precipitation Data

Precipitation data quality is excellent (±5%) with the exceptions where records for short periods were estimated. The estimated data are coded with an "E" and should be considered good (±10%).

3.2 Streamflow Data

Streamflow data quality is at least good (±10%) for all ranges of flow depths at all stations except for the periods of records obtained prior to flow control modifications at the six stations as shown in table 1. Flow values equal to or less than rates shown (table 1) which occurred prior to control modification could be as much or more than 20% in error. Discharge data for flow values greater than values shown for these periods are good (±10%).

Sediment accumulations upstream of the weirs created problems of varying degrees, depending on the watershed soil types and channel transport capabilities above the different streamflow measuring stations. Occasional sediment removal was required to prevent interference with low flow measurements. Recession curve corrections were made, when required, by adjusting flow depths based on normal recession conditions.

Stilling well liners containing fuel oil were used to prevent stage recorder floats from becoming ice bound during freezing conditions.

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REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM THE NORTHWEST LAND MANAGEMENT AND CONSERVATION RESEARCH CENTER

K. E. Saxton and D.K. McCool[1/]

INTRODUCTION

Our research is to determine effective tillage and cropping systems for the Pacific Northwest Region of the United States with particular interest to the dryland farming area of Washington, Oregon, and Idaho. The Palouse area of eastern Washington and northern Idaho is an area of specific interest because of its high productivity, severe erosion, and water-quality problems.

Research scientists at this location conduct a wide variety of research requiring field measurements. Much of the research involves small plots for defining the effects of current or proposed crop-tillage combinations on the soil, runoff, erosion, and crop productivity. In addition, several small watershed projects have been conducted requiring detailed climatic, streamflow, and runoff quality measurements. Research of this type at this location has been nearly continuous since 1934. Much of the investigation is conducted at the Palouse Conservation Field Station located 2 miles northwest of Pullman, Washington, and at Washington State University. In addition, many outlying plot areas in Washington and Idaho are utilized to obtain other environmental, crop, and farming conditions.

The climate and topography of this region provide several specific research problems. Most precipitation occurs in the winter months largely as very low intensity rain but interspersed with occasional significant snow accumulations. Shallow frozen soil, which severely limits infiltration, occasionally occurs prior to winter rain or snowmelt. Precipitation amounts are strongly related to elevation and orographic features. Erosion and sediment concentrations from the extremely steep Palouse farmlands are very high. Essentially, all runoff and erosion occur in the winter months.

DATA ACQUISITION

The acquisition of data in our region requires maintaining excellent measurement calibration and reliability during the winter months because that is when essentially all hydrologic activity occurs. Cold weather, snow, ice, and muddy and frozen soil must be dealt with. Temperatures frequently hover near the freezing point causing precipitation to vary from rain to snow, often within the same event period. Precipitation and runoff rates are normally very low intensity, but significant erosion and chemical movement occur during these cold conditions making sampling difficult.

Several specific data problems and some solutions are listed in Table 1. For precipitation, measuring snow and maintaining clocks in cold weather are the two

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1/ Research hydrologist and agricultural engineer, respectively. A contribution of the Land Management and Water Conservation Research Unit, Agricultural Research Service, U.S. Department of Agriculture, Pullman, Wash. 99164-6421.

most difficult problems. Streamflow measurement and sampling can be adequately accomplished using enclosed shelters, but this is difficult and expensive. Much of our instrumentation is quite old, and very limited applications are made of modern electronics and data acquisition systems.

DATA QUALITY

The quality of precipitation and streamflow data is largely related to instrument design and reliability, whereas sediment and chemical data are more determined by sampling frequency and representativeness of the streamflow. The instrument problems can be improved by design and the sampling errors minimized by knowledge of the streamflow and constituent characteristics.

A summary of data quality evaluation for recent measurements by our scientists is given in Table 2. With due attention to the climatic factors, most measurements are reasonably accurate. Measuring snow and rain under windy conditions and very low intensities causes some loss in quality, but there is no good standard for comparison. Sampling for sediment and chemicals is very labor intensive and not entirely satisfactory from either streamflow or catch tanks. Just as important, there are other measurements, such as runoff and samples from large plots and small watersheds, that we just do not attempt because a reliable, accurate, and economical instrument system is not available. That is, we only do measurements that are "good" or better quality, but there are others that should be made.

RECOMMENDATIONS FOR INSTRUMENT RESEARCH

Precipitation

Wind effects on catch.--Review previous research to decide if current gage shapes and wind shields are adequate. Some quick wind tunnel experiments (e.g. at Colorado State University) may be beneficial.

Recording system.--The accuracy and reliability of the time-depth recordings for raingages could easily be improved with some innovative design. For example, a small electronic data storage with a microprocessor could provide pre-programmed data points using typical breakpoint or other criteria.

Streamflow

Installation and calibration guidelines.--Many sites provide opportunity for installing currently available pre-calibrated or field-calibrated devices. But those required to do the installation often do not have the training or guidelines to avoid significant errors in instrument selection, installation, or calibration. A knowledgeable hydraulics engineer should be available (perhaps required) to review each site. And a more accurate and detailed manual for each standard device should be available with actual field conditions and allowable variances discussed, not just laboratory ratings.

V-notch weir calibrations.--The V-notch broadcrested weir has been extensively used, but recent results show that approach channel conditions can significantly alter the ratings (see References). All knowledge of this weir from both laboratory and field ratings should be accumulated and published. This would allow evaluating past and current installations and correct recommendations for future applications. The interaction with sediment deposition should be included.

Measuring sediment-laden flows.--Most current devices partially or completely fail to accurately measure flows with high sediment concentrations. A new device with both accuracy and reliability is needed. Some recent work using turbulence walls upstream of V-notch weirs and super-critical flumes shows promise. A new approach to measuring water stage is a key element to avoid stilling well and intake design and plugging problems. A complete but simple system for large plots or small watersheds is a major need to our research.

Rapid streamflow measurement.--One of the largest deterrents to accurate field calibration of streamflow devices on small watersheds is rapid rate measuring methods. The traditional current meter methods do not work because of rapid stage changes and debris. With innovation, modern electronics, and the latest electronic current meters, a rapid system for flow rate determination of small streams is entirely possible. With one rapid sweep across the stream, a microprocessor meter could readily integrate depths, velocities, and flow rates.

Low rate streamflow.--Some small plots need low rate flow measurements. Most now adapt the tipping bucket principle, but it plugs with sediment, freezes, and has questionable accuracy. A new device is needed. Many plot installations need this capability with associated sampling opportunity.

Sedimentation/Water Quality

Required sampling frequency.--This is a large unknown in all sampling. A summary of existing experience at many locations would suggest guidelines. A special symposium devoted to this topic would stimulate these papers. A method of continuously monitoring key streamflow constituents may provide a real-time opportunity to select samples.

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Table 1. Data Acquisition System

Instrument description	Problem situations	Action taken to insure data quality
2.1 Precipitation:		
Weighing raingages	Low snow catch	Added wind shields, but not a complete solution
	Collection of snow on inside of orifice	Brush snow into gage at changing--a partial solution
	Clock stoppage	Maintenance, but still lose some data; duplicate gages established
	Need good time resolution, but also weekly chart for daily amounts	Set up duplicate gages, one with daily and one with weekly time scales
Heated, tipping bucket gages	Failed to record low-intensity rain and snow because heat evaporated the incoming water before recording occurred	None possible--all data voided
2.2 Runoff/Streamflow/Groundwater:		
Streamflow gaging	Calibration (in rapidly varying streams, particularly)	Installed precalibrated weirs; verified with volume and current meter measurements; assured that the installation closely conformed to laboratory calibration conditions (matching lab and field conditions is not always possible)
	Sediment deposition in approach channels	Manually cleaned as needed to avoid rating interference
	Stage well intake lag and plugging	Used large intakes--which then gave some wave action and well deposition
	Weir and stage well icing	Placed a heated shelter house over entire weir and approach channel which housed all recorders and samplers
	Stage recorder failure	Frequent attention and dual recorders

Table 1. (continued)

Instrument description	Problem situations	Action taken to insure data quality
	Inaccuracies of low rate-long duration flow with sediment	Modified a tipping bucket method, but not yet satisfactory or reliable
2.3 Sedimentation:		
Suspended sediment streamflow sampling	Assurance that pumping sampler intake gave correct representation as located	Compared pumping sampler with hand samples
	Backflush of pumping sampler loosened bottom sediments in approach channel in low flow conditions	Backflush omitted and sampler flushed by a direct flow which was discharged below the weir
	Electronic failure of P.S. 69 samplers	Electronic technician made extensive revision of control systems on all samplers
Sediment in runoff collection tanks	Obtaining representative sample for concentration determination	Developed agitating and proportional sampling device
2.4 Water Quality:		
Chemical concentrations	Phosphorus contamination by plastic bottles	Changed bottles after problem identified
	Degradation after sampling	Rapid transport and analysis method implemented
Bacteriological concentrations	Representative sampling by automatic sampler (P.S. 69)	Verified with numerous hand samples

Table 2. Data Quality Evaluation

Description of current stations	Number of stations	Estimate of data quality	Special problems and comments
3.1 Precipitation:			
Non-recording unshielded	2	Snow - fair Rain - good	Shielding would help snow catch
Recording - shielded	8	Good	
Heated tipping bucket	2	Poor	Data are invalid for low snow and rain intensities
3.2 Runoff/Streamflow/Groundwater:			
V-notch, broadcrested weir	1	Excellent	Weir crest was sheet aluminum and channel very stable, low sediment watershed
Drop-box weir	1	Excellent	Very small scale used on small grass watershed
H-flumes	2	Good	Some problems with icing and sediment
Total catch tanks	36	Good	Limited capacity requires frequent servicing; applicable only to small plots; flow rates not accurate if available
3.3 Sedimentation:			
P.S. 69 samplers	2	Good	Severe electrical and pump problems in project initialization
Proportion sampling	36	Good	Tank sampling by stirring and hand sampling is difficult and time consuming; pump agitation with sampling splitters has helped
3.4 Water Quality:			
Chemical and bacteria	36	Good	Proportional hand sampling with good procedures for transport and analyses

CHAPTER 'C' Moorefield, West Virginia

By James B. Burford[1]

1. INTRODUCTION

During the 1950's an increase of interest in chiseling shallow soils underlain by shale, in the Appalachian Ridge and Valley areas of Pennsylvania, Maryland, West Virginia, Virginia, Kentucky, and Tennessee, focused attention on the need for research data related to the hydrologic responses from this land management. This need prompted the Agricultural Research Service (ARS), in cooperation with the Soil Conservation Service (SCS) and the West Virginia Agricultural Experiment Station to initiate hydrologic studies at a site located near Moorefield, West Virginia. The general objectives were to study basic factors affecting the hydrograph of surface runoff from pasture on shallow soils formed on shale and to evaluate the effect of shale chiseling on water yield and the hydrograph of surface flow (1)[2].

Four small areas, two pairs of adjacent watersheds, less than 10 acres each (4.048 hectares) in size (table 1) were selected and instrumented for precipitation and stream flow with complete records starting June 1958, and continuing through January 1967.

All precipitation and stream flow data have been tabulated and computer processed. These data, in breakpoint form, are stored in the ARS Water Data Bank, maintained by the ARS Water Data Laboratory. Copies are also on file with the Agricultural Engineering Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Data summaries together with watershed descriptions, cover and cropping conditions information are included in hydrologic data publications (2).

2. DATA ACQUISITION

Data collecting instruments were serviced by local SCS technicians who mailed the chart type records to ARS headquarters for processing. During the construction period and through the first few years of operation the project was maintained by the ARS Northeast Watershed Research project at Coshocton, Ohio. Maintenance responsibilities incuding data tabulating and processing, were shifted to the ARS hydrology project at Blacksburg, Virginia for the later years of records.

2.1 Precipitation Data

Precipitation stations with continuous chart type recorders operating with 12 hr. time scales, one per each pair of watersheds (table 1), were used to obtain precipitation informaton. One additional precipitation station operating with 192 hr. chart was located in the general area. Standard can type gages were used at all three

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[2] Underscored numbers in parentheses identify references cited and listed at end of chapter.

Table 1.--Experimental Watersheds - Moorefield, West Virginia

Location Name (Ident No.)	Periods of Records (mth./day/yr. From	To	Watershed Areas (Acres)	Precipitation Station[1/] Designation	Code
W-1	6/01/58	1/01/62	8.25		
(66001)	1/01/62	12/31/67	8.57	R-1(A)	P01R01
W-2	6/01/58	1/01/62	10.06		
(66002)	1/01/62	12/31/67	9.73	R-1(A)	P01R01
W-4 (66004)	6/01/58	12/31/67	6.32	R-3(C)	R03P03
W-5 (66005)	6/01/58	12/31/67	9.55	R-3(C)	R03P03

1/ Gages operated with 12 hr. charts.
Precipitation gage R-2(B) (R02P02) Located near 66002 Watershed operated with 192 hr. chart.

Figure 1.--Streamflow measuring station below a Moorefield, West Virginia watershed. 4.5 ft. H-flumes of this type, were used on all four watersheds.

stations for precipitation volume checks.

2.2 Streamflow

Precalibrated 4.5 ft. H flumes (3)were used as flow controls below each watershed (fig. 1). Thermostatically controlled heating cables, embedded in the flume floors, and heating elements in the stilling wells were used to prevent cold weather flow measuring problems.

Continuous streamflow depths were obtained for the complete periods of record for all four stations, using chart type recorders with 24 hr. time scales.

The lack of distinct watershed divides around the perimeters of the four study areas created some concerns as to the exact areas. Late in 1961 detailed surveys were made to determine the natural divides and border ridges were constructed where possible. This resulted in the areas of watersheds W-1 (66001) and W-2 (66002) being changed as shown in table 1.

3. DATA QUALITY EVALUATION

3.1 Precipitation Data

Precipitation Data data quality is excellent ($\pm$5%) with the exception when records of short periods were estimated. The estimated data are coded with "E" and should be considered good ($\pm$10%).

3.2 Streamflow Data

Streamflow data quality is excellent ($\pm$5%).

Heating cables installed in the concrete floors of the H flumes ceased to operate at two of the stations and had to be replaced.

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